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7. Author(s)
S. Tomlinson, J. Buckingham, R. Erwin, B. Carpenter, and S. Wilhoite

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9. Performing Organization Name and Address
Southwest Research Institute
6220 Culebra Road
Post Office Drawer 28510
San Antonio, Texas 78228-0510

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16. Abstract
Physiological response (heart rate) of captive wild birds to approaching aircraft during the take-off roll was determined during a Phase I (laboratory) and Phase II (field) study.

Methods and materials designed during the laboratory study were used during the field test to collect data on birds exposed to standard-body and wide-body aircraft during regularly scheduled departures from San Antonio International Airport.

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EXECUTIVE SUMMARY

Methods to obtain physiological response (heart rate) of captive wild birds to approaching aircraft during the take-off roll were developed during a Phase I (laboratory) and Phase II (field test) study.

The laboratory study exposed birds to video scenes of aircraft during the take-off roll. Equipment to monitor the heart rate of the bird included a harness fitted with an Electrocardiogram (ECG) transmitter. The test birds were gulls [Larus atricilla) and feral pigeons (Columba livia domestica) captured on or adjacent to Corpus Christi and San Antonio International Airports. Pigeons acclimated to airport sights and sounds were compared with pigeons not acclimated to airports. The video scenes of approaching aircraft caused heart rate increase in the unacclimated pigeons several seconds sooner than the acclimated birds, and the unacclimated pigeons were more responsive to the sound, as well as the sight, of approaching aircraft. Gulls and pigeons acclimated to airports used sight first, then sight-and-sound, and sound last as an indication of approaching aircraft during the video test.

Methods and materials designed for use during Phase I were used during the field test to collect data on birds exposed to standard-body and wide-body aircraft during regularly scheduled departures from San Antonio International Airport.

The test birds equipped with ECG transmitters were positioned beside the active runway in individual cages.

The bird's heart rate data were collected and stored on equipment in a mobile laboratory placed at the safety lines of a taxiway that crossed the active runway at the 4000-foot mark. This distance from the start of the take-off roll gave the bird a view of aircraft during the rotation phases.

Aircraft tested included the 737-200, 737-300, 727-100, 727-200, DC-9, MD-80 and 767-100. The 24 test birds were exposed to over 100 aircraft departures during the test period from January through May 1990. The aircraft rotation was identified on the recorded data when the nose wheel left the ground during the take-off roll.

Statistical analysis of the recorded data was conducted and results from the analyses of variances were tested at the 5 percent level of significance. Birds exposed to the 767 wide-body aircraft experienced statistically higher maximum heart rates on the average than the other four (standard-body) aircraft. Gulls had a significantly higher average maximum heart rate than pigeons when tested at the aircraft rotation point response interval. The average of maximum heart rate response during the maximum sound response interval showed a higher percent change after take-off than before take-off. Gulls did not indicate by maximum heart rate response as much change as the feral pigeons during the maximum sound response interval when the data were normalized by control tests.

Analysis of the closure rate of the aircraft to the test bird location indicated the bird response did not change significantly until the aircraft approach was within 1000 feet of the bird. The aircraft velocity rate increase over this distance closes on the bird between 150 to 200 feet per

second. The bird would have about 5 seconds to clear before impact with the aircraft. Early warning devices to alert the bird to approaching aircraft would need to be deployed prior to 10 seconds to allow the bird time to depart the runway area.

PHASE I--DESIGN OF LABORATORY EXPERIMENTS

INTRODUCTION.

Birds living by or near an airport present a hazard to moving aircraft, especially air carriers with jet engines. These engines contain large air intakes that allow foreign material, such as a bird, to be drawn into the moving parts of the engine. This could result in engine failure and loss of the aircraft, crew, passengers, and cargo. Designing an early warning system to remove birds from the path of approaching aircraft could reduce this problem, but it requires an understanding of the bird's detection and reaction time to the sight-and-sound of approaching aircraft.

A two-phase study was initiated in order to support the presumptive evidence for the hypothesis that bird strikes could be reduced if the bird knew in time that the aircraft was approaching. Phase I was the design of laboratory experiments, and Phase II was the field measurement of birds' physiological responses to actual aircraft take-off.

OBJECTIVES.

Phase I (laboratory study) consisted of the following:

1. Selecting bird species known to have caused problems in and around heavy traffic airports.

2. Incorporating living birds in laboratory experiments involving physiological data collection during their viewing of videotapes of aircraft during the take-off roll.

3. Integrating birds, equipment, and procedures to facilitate a successful field trial study. The Phase II field studies exposed the bird model to specified aircraft during actual take-off rolls at a high traffic international airport.

4. Making the observation in item 2 above on conditioned (collected near an airport) and unconditioned (collected far away from an airport) birds and comparing the results.

5. Exposing birds to the sight-and-sound of certain aircraft and exposing the birds to sight-only and sound-only experiments while collecting physiological data for later analysis.

MATERIALS AND METHODS.

BIRD MODELS. Studies of bird flocks that live and feed around airports have confirmed the danger they represent to aircraft. The Federal Aviation Administration (FAA) Technical Center has collected data on bird ingestion by large, high bypass ratio (HBPR) turbine aircraft engines. Of the 85 species of birds considered, the gull (family Laridae) was ingested most often. Thus, the gull was chosen as one of the bird models for the study.

Another bird on the FAA's most active list was the domestic pigeon or rock dove (Columba livia domestica). It is the most common bird in the San Antonio International Airport area and is also a major problem in and around Kelly Air Force Base, San Antonio, Texas. Therefore the rock dove, both wild and tame, was chosen as the second bird model.

Capture of the gulls required the investigating officer to obtain an amendment to the Scientific Permit No. SP226 from the Texas Parks and Wildlife Department and an amendment to the Scientific Collecting Permit No. PRT-717791 with the Department of the Interior, U.S. Fish and Wildlife Service. The amendments to the permits were issued and the bird collecting was initiated for both gulls and pigeons.

The gulls (Larus atricilla) were captured adjacent to the Corpus Christi Airport and Naval Air Base on the Texas gulf coast. A mist net (Nebba Type CTX, 12 meters long by 2.6 meters high with four shelves and 61 millimeter (mm) mesh 110 denier) was used to trap the gulls; aluminum extension poles were used to place the net in the gulls' flight path. Having been captured, the gulls were placed in ventilated, closed wall, fiberglass cages to avoid the risk of injury inherent in wire cages. The gulls were transported to the SwRI aviary for continued care and maintenance. There, a special diet regimen was prepared.

A gull diet ration (figure 1) was a blended mixture of poultry maintenance ration, canned cat food, raw carrots, and hard boiled eggs. Fish pieces were placed on top of the daily ration. The mixture was freshly made every day. The daily ration was placed on the floor of the gull cage in a stainless steel pan inside a larger stainless steel wading tray (figure 2). A separate bathing tray was provided inside the cage. The floor of the cage was covered with sand that was replaced as needed to maintain a clean environment. The water in the feeding tray and bath was changed daily, and the feeding and watering utensils were cleaned daily.

Heat lamps were installed in the feeding and watering areas for supplemental warming during inclement weather. The north end of each flight cage containing the birds' roosting area was enclosed to provide protection from the weather.

Pigeons unconditioned to airport traffic were purchased from a supplier 40 miles from the San Antonio International Airport, while conditioned wild pigeons were captured adjacent to the airport. The two groups of pigeons were housed separately with no physical contact allowed.

The pigeons' diet was Purina™ Pro-13 No. 5418 supplemented with pigeon grit No. BM-41 in "ad libitum food" tray containers. Water was provided in wire covered water containers maintained at a depth of five centimeters (cm).

Daily care included cleaning of the feed and water pans, providing the daily food ration, and checking the bird's health and physical appearance. Any physical damage or sign of ill health in the birds was reported to the project veterinarian. All birds were identified by aluminum leg bands and records were maintained in the aviary office.

FIGURE 1. GULLS DIET

FIGURE 2. GULLS AT FEEDING TIME

AVIARY. The aviary was located in a quiet, wooded area separate from the other laboratories. Support facilities in the aviary area (figure 3) included birdcages, isolation cages, diet kitchen, office observation area, and storage shed for the cage maintenance material.

EXPERIMENTAL DESIGN. Preparation for and conduct of the laboratory experiments included the following tasks:

1. Established methods of recording, storing, and retrieving physiological data for statistical reduction.

2. Determined the effects of physiological monitoring devices on the birds' responses to video images of aircraft during the take-off roll.

3. Exposed each bird to the sight-and-sound, sight-only, and sound-only of video scenes of five aircraft during the rotation phase of the take-off roll.

4. Compared data obtained from conditioned birds (wild birds living near an active airport) and unconditioned birds (tame birds living away from an active airport) and between two species of birds (pigeons and gulls).

A method was developed to expose each bird to the video image in an acoustically isolated test chamber facility. Figure 4 shows the electronic equipment for conducting transmitter receiver or direct wire physiography experiments. The viewing area of the test bird was restricted to the video monitor by a closed tunnel contained within the acoustic chamber room. This arrangement reduced outside distractions. The tunnel was constructed of plywood with the interior wall surface lined with black foam, 1.9 cm thick. The tunnel measured 150 x 73 x 56 cm. One end of the tunnel fit against the video monitor screen which contained two speakers; the other end was open to the birdcage, which was accessed through a side door in the tunnel. The bird-cage measured 33 x 41 x 27 cm and was positioned 113 cm from the video screen. The transmitter receiver formed the top of the cage. A sound meter was also positioned at the birdcage area, and the video, audio, transmitter receiver, and sound meter wiring exited the tunnel and passed through the acoustic chamber room wall to the adjacent video, strip chart, and magnetic tape recorders.

LABORATORY TESTS. The laboratory tests for gulls and pigeons followed these guidelines:

1. Each experiment was logged in a laboratory notebook, including the individual bird identification and date.

2. Each bird tested was randomly withdrawn from its cage, identified with a leg band, and conditioned to a wire cage measuring 60 x 60 x 45 cm. After the conditioning in the aviary observation room for 2 hours on the day before a laboratory experiment, the bird was returned to the outside holding cage.

3. On the test day, the bird was captured in the holding cage and hand-carried to the testing laboratory where identification was confirmed.

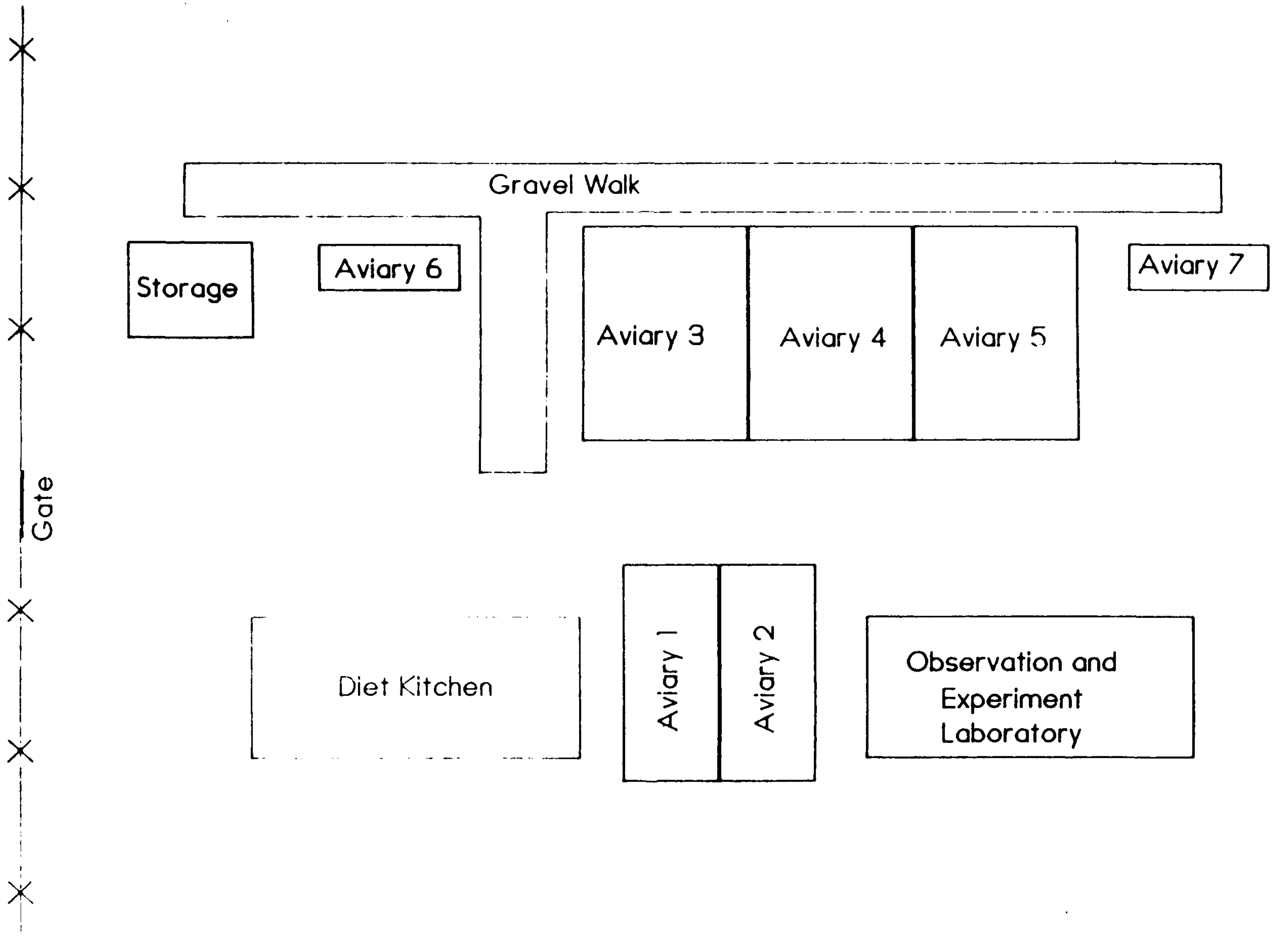
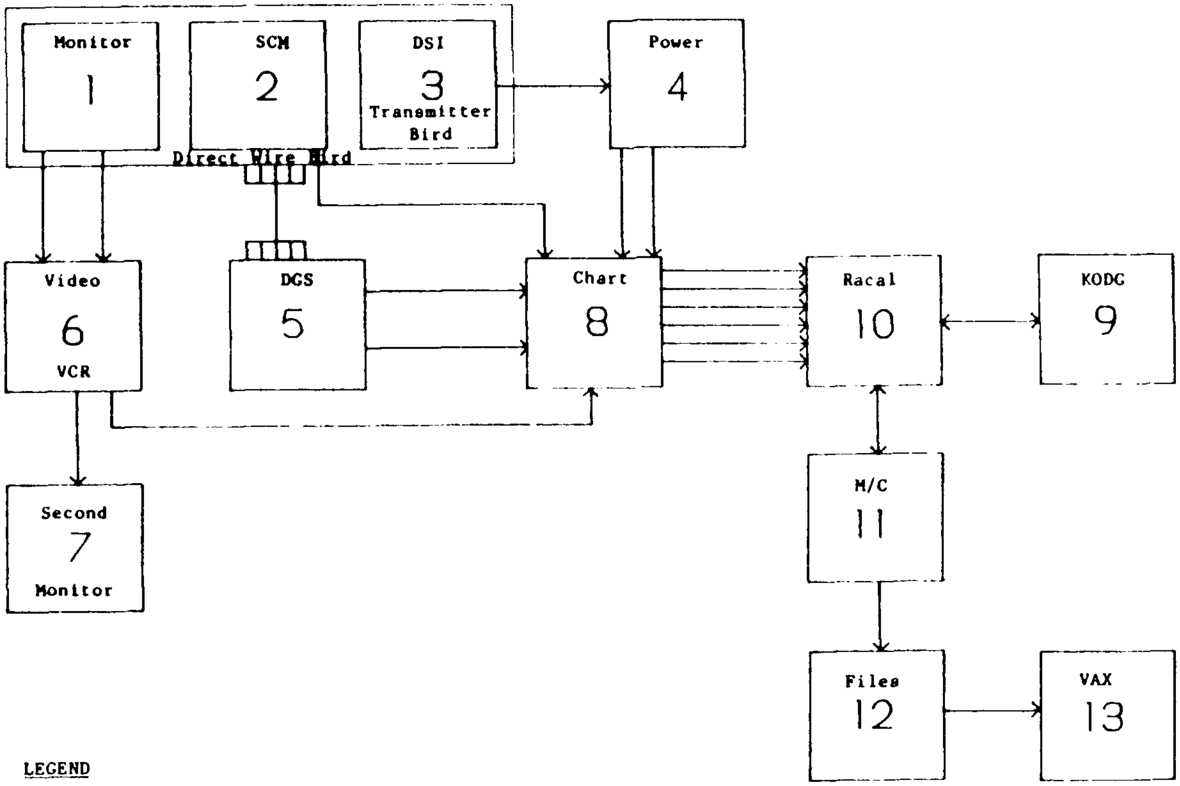


FIGURE 3. AVIARY SUPPORT FACILITIES



LEGEND

1. 26" GE Color Monitor

2. Sound Level Meter-General Radio USA 1565-B
Permissible SLM

3. Data Sciences Transmitter/Receiver. Transmitter Model TA10CA - F 40.
Receiver Model RA 2610
Note: Test bird with transmitter connected for biopotential signals was located in the exposure cage under receiver location.

4. Physiotel System Tester W/6 Ext. Pwz Jcks and 110 VAC Supply

5. DGS (Data Graph System) 4-Channel Model 76102 with EEG/EKG Amplifier and Impedance Pneumograph Amplifier. Note: For direct wire experiments the five wire leads were connected to the test bird.

6. Sony Videocassette Recorder

7. Sony Trinatron Component TV KX-1211HG (Second Monitor)

8. Gould 6-Channel Chart Recorder with Three Universals, Two Biotachs, and One Integrator

9. KODE TCLL Model 300 Time Code Generator

10. Racal 14-Channel Magnetic Tape Recorder

11. Masscomp MC5500 Super Microcomputer

12. Labeled Disk Files

13. Data for Statistical Analysis

FIGURE 4. EQUIPMENT SHOWING INTERFACE OF TWO SYSTEMS. FLOW TO NUMBER 4 (SYSTEM 1) IS TRANSMITTER AND FLOW TO NUMBER 5 (SYSTEM 2) IS DIRECT WIRE TO PHYSIOGRAPH

4. In the testing laboratory, the bird was hand-held while the necessary body harness, transmitter, and direct lead wires were connected.

5. All electronic test equipment and recorders were turned on, checked out, and made ready for the day's test procedure prior to placing the bird in the test facility video viewing cage.

6. The bird was placed in the video viewing cage, and the test was started after proper operation of the test systems was confirmed.

7. The test was started with a video sight-and-sound program and followed by either a sight-only or sound-only video program. The sight-only and sound-only experiments were alternated from bird to bird.

8. A repeatability test was run on three consecutive birds to detect whether the birds' responses would change after repeated exposure to the test.

9. Data stored on magnetic tape were transferred to a Masscomp computer for statistical analysis. Date and time were checked using the test log book to assure accuracy.

Slight changes in the test protocol are described below and involved the method of bird identification and the conditioning period of gulls:

1. The tame pigeons (unconditioned) were banded on the leg as squabs by the supplier and this number was used when the adult bird had a band. The unbanded tame birds, wild pigeons, and gulls were otherwise banded by the use of a modified aluminum poultry leg band custom cut to the individual bird.

2. The conditioning of the gulls to a wire cage the day before a test was subsequently eliminated because of the birds' tendency to hit the wire sides and injure themselves while trying to escape.

3. Gulls adapted well to the test environment after they were outfitted with the test equipment and placed in the darkened test tunnel environment prior to the test; attempts to escape were eliminated when the video scene came on.

4. It was recommended that when the field test on the active runway commenced, the gulls' cages be covered until they were in place at the exposure site and all equipment was ready. This assisted in preventing physical damage to the birds and the equipment.

VIDEO TEST SCENE. A video camcorder (RCA Model 300) was used to videotape the aircraft take-off scenes at the San Antonio International Airport. Automatic focusing and remote control were available on the camera. Permission to videotape was received through the Airport Operations Office. SwRI personnel were escorted to the runway sites by airport personnel in accordance with their established safety regulations, and numerous take-offs were taped during a 2-hour period. The videotape was reviewed and edited to make up the test scenes. Figure 5 shows the runway distance and angle from the aircraft's rotation point (lift-off) during the take-off roll toward the camera position. Three camera locations were used; two 175 feet from the runway and one 18 feet from the runway.

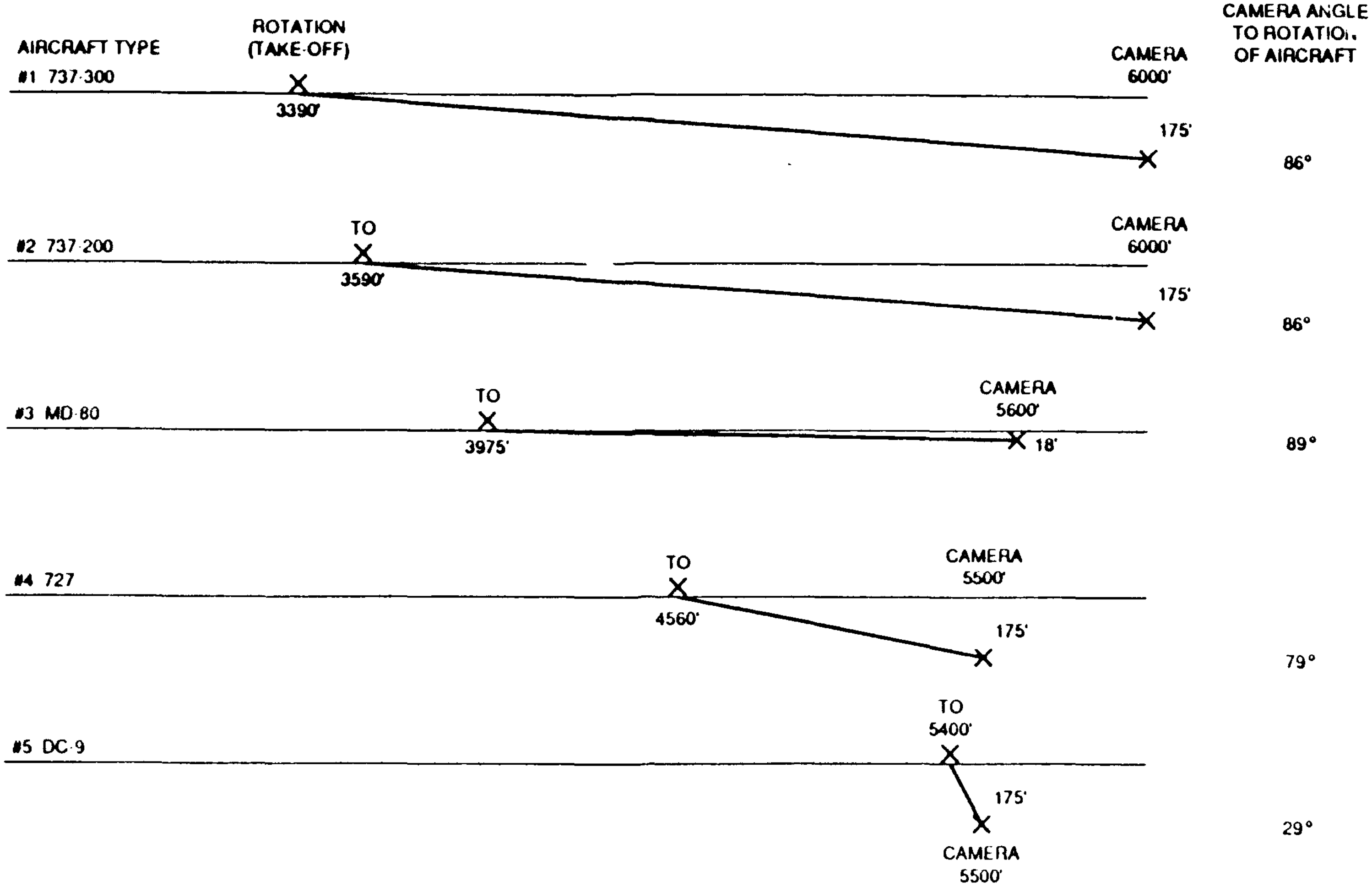


FIGURE 5. DISTANCE AND ANGLE OF VIDEO CAMERA FROM AIRCRAFT ON RUNWAY

The edited videotape followed the sequence illustrated in figure 6. A take-off sequence included a blank scene, runway scene, take-off rotation scene, and runway scene followed by a blank scene. Each of the five take-offs followed the same sequence and involved about 20 minutes of total test time.

During the laboratory test, as soon as the video sight-and-sound test sequence was complete, the tape was rewound and either the sight or sound channel of the videotape was used during the next sequence. The complete sequence of three tests kept the bird in the test facility about 1 hour; this did not appear to cause fatigue in the test bird. Handling of the test birds was kept to a minimum by using this method of presenting continuous video scenes separated by several minutes of blank scenes.

An event marker tone (1 kilohertz (kHz), 500 milliseconds (ms) was introduced on one audio channel of the tape during the editing process; it was automatically transferred to the magnetic tape and strip chart recorders during a test run. The audio channel was left unaltered and was connected from the videotape recorder to the video monitor in the bird testing chamber in the usual fashion.

BIRD HARNESS AND TRANSMITTER. A cloth harness with a back pack pocket for the transmitter was constructed to fit the pigeons and gulls. Figure 7 shows the harness and transmitter; figure 8 shows the lead wires being connected to the bird; and figure 9 shows the bird with the transmitter installed on the harness and ready for testing.

The transmitter was a self-contained Data Sciences Incorporated (DSI) model TA1OCT-F40 with a built-in antenna, a battery, and an on and off switch controlled by an external magnet. Battery life was estimated at 6 months, with a 4-month guarantee. The lead wires were 15 cm in length and the complete transmitter unit weighed 7 grams. The biopotential signals collected contained both electrocardiogram (ECG) and electromyograph (EMG).

The carrier frequency was 455 kHz (AM IF frequency) on the AM radio band and had a gain calibration of 320 hertz (Hz). The recommended cage size for the transmission distance was 42 x 42 x 25 cm. The unit was held near an AM radio tuned to the low end of a band to verify the on and off mode of the transmitter; a tone was heard on the AM radio when the transmitter was on. The receiver power supply could handle up to six units.

The transmitter lead wires were 15 cm in length and were modified with a small gold-plated safety pin for subcutaneous attachment of the bird. Figure 8 shows the lead attachment (modified Lead II ECG). The right lead was attached medial to the humerus and scapula (right wing) and the left lead near the last rib in the left costal arch area.

DIRECT WIRE PHYSIOGRAPHY. Experiments were connected using a five-pin direct wire from the bird to the physiography. A Datagraph System Model 76102 with ECG preamplifiers and an impedance pneumograph amplifier were used to interface the signals with the strip chart recorder and magnetic tape recorder (see figure 4).

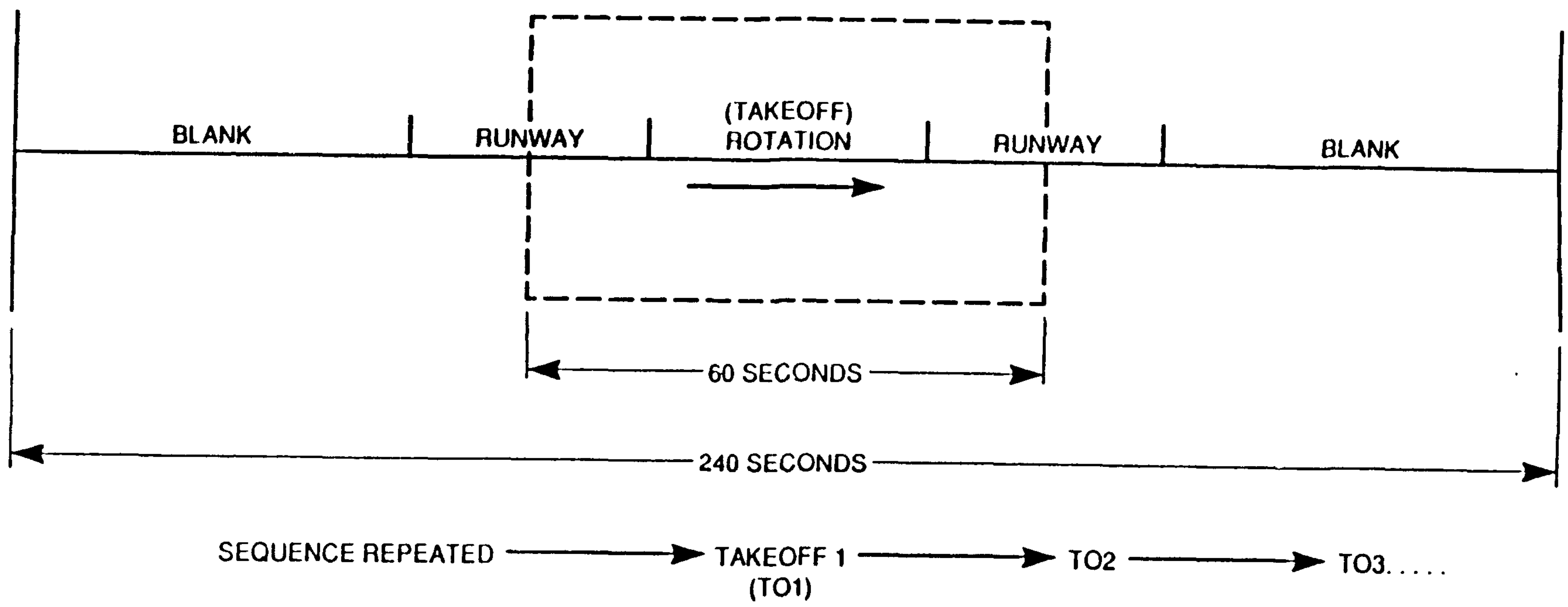


FIGURE 6. VIDEO EVENT SEQUENCE

FIGURE 7. BIRD HARNESS TRANSMITTER

FIGURE 8. TRANSMITTER LEAD-WIRE CONNECTION

FIGURE 9. BIRD WITH TRANSMITTER

The ECG lead connection was the same as described for the transmitter used with, the exception of a right leg reference ground modified to attach near the bird's mid-line lower sternum cartilage area for the ECG signals. The impedance respiration leads were connected across the upper abdomen, lower rib-cage area to take advantage of the large air sac movement in the visceral area. The model required five-wire leads connected to the bird.

The respiration impedance pneumograph signals were usable data in a quiet bird in the laboratory setting, but motion artifact during a fright stimulus interfered with the accuracy of the respiratory frequency count. Several experiments were conducted using the direct wire leads and are reported separately from transmitter-collected heart rate data.

TECHNICAL PROBLEMS. Due to drift in the initial Biotelemetric FM transmitter, we had difficulty duplicating the method used by Grant et al. (reference 1) for modified impedance pneumography in FM ECG telemetry. Using this method, one of the two transchest ECG leads was to be biased with a 20-kilohm resistor between the positive battery terminal and one side of the ECG input amplifier. The technique was designed to modulate the ECG with a large, low-frequency respiratory component, thus providing a multiplexed respiratory and ECG signal. The two signals were then to be separated by selective (bandpass) filtering.

The Biotelemetric transmitters that were available at the start of the laboratory phase operate in the 88 to 108 megahertz (MHz) commercial FM band. They were light-weight (<2 grams), had a DC 10 kHz frequency response, and would have provided physiological parameters in a light-weight (1 gram) package that could be worn by the bird with ease. Unfortunately, two problems were identified in practice. First, the small sealed transmitter was not crystal controlled and would drift across several strong local FM station signals during the hour needed for a complete experiment. Good signals were obtained in a quiet laboratory, but frequency drift resulted in interference from local stations which obscured the ECG/respiratory signal. The second problem was also related to carrier frequency drift. Due to the simple transmitter oscillator design, the carrier would sinusoidally drift in the respiratory frequency range. Thus, the multiplexed respiratory signal was obscured by transmitter drift. Methods for improving the Biotelemetric transmitter performance at low frequencies were determined to be cost-prohibitive.

After several attempts at RF-shielding and moving the experiment to a partially RF-shielded enclosure (-30 decibel (dB)), the decision was made to try the DSI AM low-frequency, short-transmission distance transmitter (7 grams). This transmitter was characteristic of standard research-quality biomedical transmitters and had a 1-100 Hz frequency response. The 1 Hz low-end response was approximately that of the normal respiratory rate. Thus, the DSI transmitter would not be suitable for the Grant et al. technique. An attempt was made to use ECG baseline shift as an indicator of respiration, but this proved unacceptable due to the limited low-frequency response.

SIGNAL CONDITIONING. Primary signal conditioning to reveal heart and respiration rate depended on the different bird ECG/RESP interfaces used. For the case of the DSI transmitter system, the QRS detection TTL pulse from the DSI receiver was used by the Gould Biotach for calculating heart rate. The

analog ECG signal from the receiver was both chart and tape recorded. This signal was also low-pass filtered at 2.5 Hz, greatly amplified, charted, and input to a Gould Respiratory Biotach.

The ECG output was processed for hardwire situations (DGS ECG/impedance pneumograph using a Gould Biotach, and the respiratory signal was processed using a Gould Respiratory Biotach. Pulses representing scaled analog rates were recorded on both strip chart and tape. Tables 1 and 2 show the channel configuration and placement of the Racal Storehorse instrumentation recorder and the Gould 6-channel strip chart recorder, respectively.

Instrumentation calibration was performed using the manufacturer's recommended procedures. A Fogg super patient simulator was used to provide known amplitude and rate signals for calibrating both hardwire and telemetry patient interfaces. The Fogg simulator provides ECG, respiratory impedance changes, blood pressure, and temperature calibrated signals and rates. A Datel DC calibration voltage source was also used.

Relative sound level was determined by rectifying and integrating the microphone output from a General Radio 1565-B sound level meter. This approximation of power was calculated using a Gould Integrator. The integrator output was updated and held for 100 ms. The peak output from the sound meter was adjusted to have a full-scale output equivalent to 100 dB. This method was to provide a relative sound level output for insuring data integrity. A sound meter with a calibrated sound level output was purchased for the second phase of the project.

<u>DATA ACQUISITION AND PROCESSING</u>. Analog heart rate, respiratory rate, and sound level were 12-bit analog/digital (A/D) converted using the Masscomp super microcomputer. A Kode time code translator/tape search unit was used in conjunction with the 1-kHz, 500-ms event marker system to appropriately index bird/date/event segments during data acquisition. The data acquisition system was semi-automated and used Masscomp's laboratory workbench interactive data acquisition package. Analog data were digitized at 16 times real-time. The effective A/D rate was 20 Hz for four channels (heart rate, respiration rate, sound level, and event trigger). Input data were filtered to prevent aliasing with Precision Filter's six pole, six zero time delay low-pass filters (80 dB/octave).

Time epochs of 60 seconds were centered on the event marker and digitized for each of the five take-off scenes and the corresponding blank transition period preceding the take-off scene. The raw digitized data was parsed and block averaged to an effective rate of 0.25 Hz. These files were stored on hard disk and archived on digital magnetic tape. A hierarchial file structure was used as a simplified data base. These individual data files were subsequently processed with a series of UNIX utilities, shell scripts, C programs, and commercial packages.

Data processing consisted of plotting raw and normalized time series data. Take-off and blank sequence data were normalized as the percentage change from baseline. Baseline was defined as the average signal value for the 10-second period starting 15 seconds before the event. Baseline values were calculated for each blank sequence prior to a take-off sequence.

TABLE 1. CHANNEL CONFIGURATION INSTRUMENTATION RECORDER

Racal Storehorse Configuration Bandwidth WB1 Filter TCH Speed $1\frac{7}{8}$ ips					
CH	SIGNAL TYPE	TYPE	VOLTAGE	UNITS	RANGE
1	Takeoff event trigger (500 Hz, 20 ms)	FM	1	RMS	±
2	Chamber sound level	FM	2	RMS	+
3	Biotach QRS detection trigger	FM	2	RMS	+
4	Heart rate	FM	2	RMS	+
5	Off tape sync	Direct	OTS	OTS	±
6	Lead II ECG	FM	5	PEAK	±
7	Odd channel flutter compensation	FM	20	RMS	±
8	Even channel flutter compensation	FM	20	RMS	±
9	Activity trigger (RECV)	FM	2	RMS	+
10	Respiration	FM	5	PEAK	±
11	QRS detection trigger (RECV)	FM	2	RMS	+
12	Respiration rate	FM	2	RMS	+
13	Respiration detection trigger	FM	2	RMS	+
14	I R I G B time code	FM	2	RMS	±
16	Voice	Direct	?	N/A	N/A

SIGNAL PLACEMENT Racal Storehorse Recorder			
CH	ODD HEAD	CH	EVEN HEAD
1	Takeoff event trigger	2	Chamber sound level
3	QRS event trigger	4	Heart rate
5	Off tape sync	6	Lead II ECG
7	Odd channel flutter compenstation	8	Even channel flutter compensation
9	Activity event trigger	10	Respiration
11	QRS event trigger	12	Respiration rate
13	Respiration event trigger	14	I R I G B time code
		16	Voice

TABLE 2. CHANNEL CONFIGURATION CHART RECORDER

CHART RECORDER CHANNEL PLACEMENT				
CH	TELEMETRY SIGNAL SOURCE	RANGE	HARDWARE SIGNAL SOURCE	RANGE
1	Raw respiration (RCVR)	N/A	Raw respiration (impedence	N/A
2	Respiration rate (Biotach)	0-100 bpm	Respiration rate (Biotach)	0-100 bpm
3	Video event marker	N/A	Video event marker	N/A
4	Lead II ECG (RCVR)	N/A	Lead II ECG (DGS)	N/A
5	Heart rate (RCVR)	0-500 bpm	Heart rate (Biotach)	0-500 bpm
6	Sound level	0-100 dB	Sound level	0-100 dB

Subsequent to visual data analysis and integrity checks using raw and normalized data, averages of normalized take-off and blank sequence data were generated and plotted for each species and repetition sequence. In addition, comparison plots of hardwire heart rate and respiration versus time were made. Normalized heart rate and sound level data for both take-off and blank sequences were transferred to SwRI's 8600 class VAX computer system for statistical analysis.

RESULTS.

OBSERVATIONS. Use of the viewing tunnel to expose the bird to the video scene reduced distractions to the bird. The foam-lined tunnel placed in the acoustic controlled chamber room gave the sound-proofing necessary to present sight-and-sound, sight-only, and sound-only experiments. Figure 10 shows the heart rate of the bird going from a blank scene to a runway scene. The blank scene and runway scene precede the take-off of a DC-9 (Scene 5). Scene 5 had more airport background noises and personnel voices than the four preceding scenes. The birds' heart rate increased more in response to the sight-and-sound than sound-only, and sight-only evoked the least response. Typically, the heart rate response increased for 4 or 5 seconds when the runway scene appeared and then decreased to a new baseline. After the bird stabilized to the new runway scene baseline, the take-off scene appeared and the heart rate increases were measured.

The physiological monitoring transmitter harness did not appear to distract the bird from the video scenes. Most of the birds displayed quiet and subdued behavior while the harness and lead wires were being attached and during transfer to the test site. Some data, such as respiration, were lost due to the bird's movement, but the ECG signals remained strong.

Figures 11 through 15 show the averaged, normalized heart rate response collected from transmitted ECG of gulls exposed to the sight-and-sound, sight-only, and sound-only tests. The sound level is presented on the graph. The sound level meter was located 113 cm from the video monitor at the bottom front of the bird test exposure cage. The monitor audio volume control was set to simulate actual levels.

Figure 11 shows a 737-300 (Scene 1). The video with sound caused the earliest heart rate response followed by the video-only, and then the sight-and-sound. The sight-only caused the greatest change from the baseline.

Figure 12 shows a 737-200 (Scene 2). The sound-only caused the earliest heart rate response followed by the video only, and then the sight-and-sound. The sight-only caused the greatest change from the baseline.

Figure 13 shows a MD-80 (Scene 3). The sight-only caused the earliest and greatest change from baseline. The sight-and-sound and sound-only heart rate response appeared about the same time. The sound-only caused slightly more change from baseline than sight-and-sound.

Figure 14 shows a 727 (Scene 4). The sight-and-sound heart rate increase appeared to start at the same time as the sound-only but the increase from baseline is greater for the sight-and-sound. The sound-only stimulus caused a longer heart rate response.

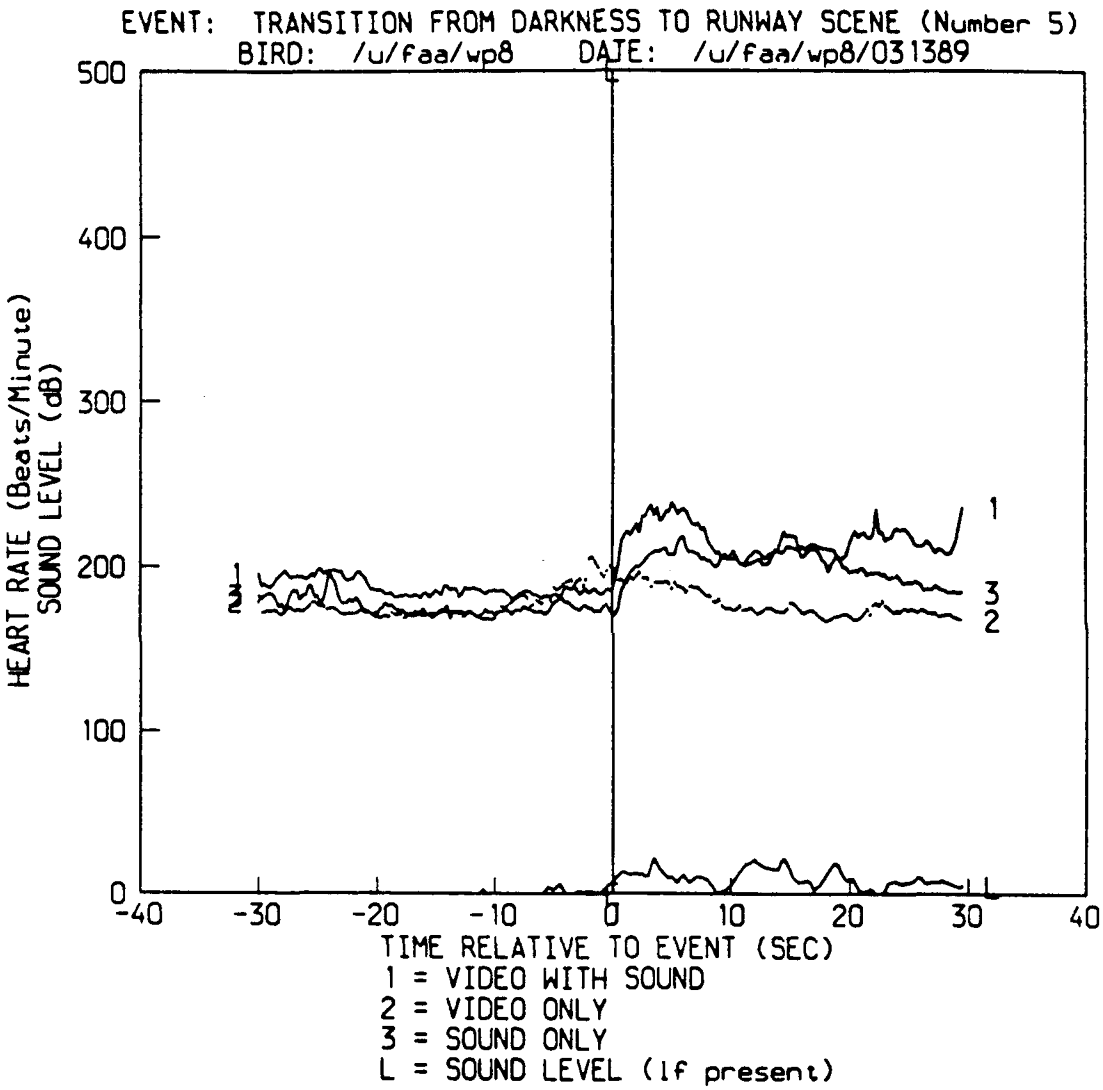


FIGURE 10. HEART RATE RESPONSE ACROSS STIMULUS SOURCES (BLANK SCENE)

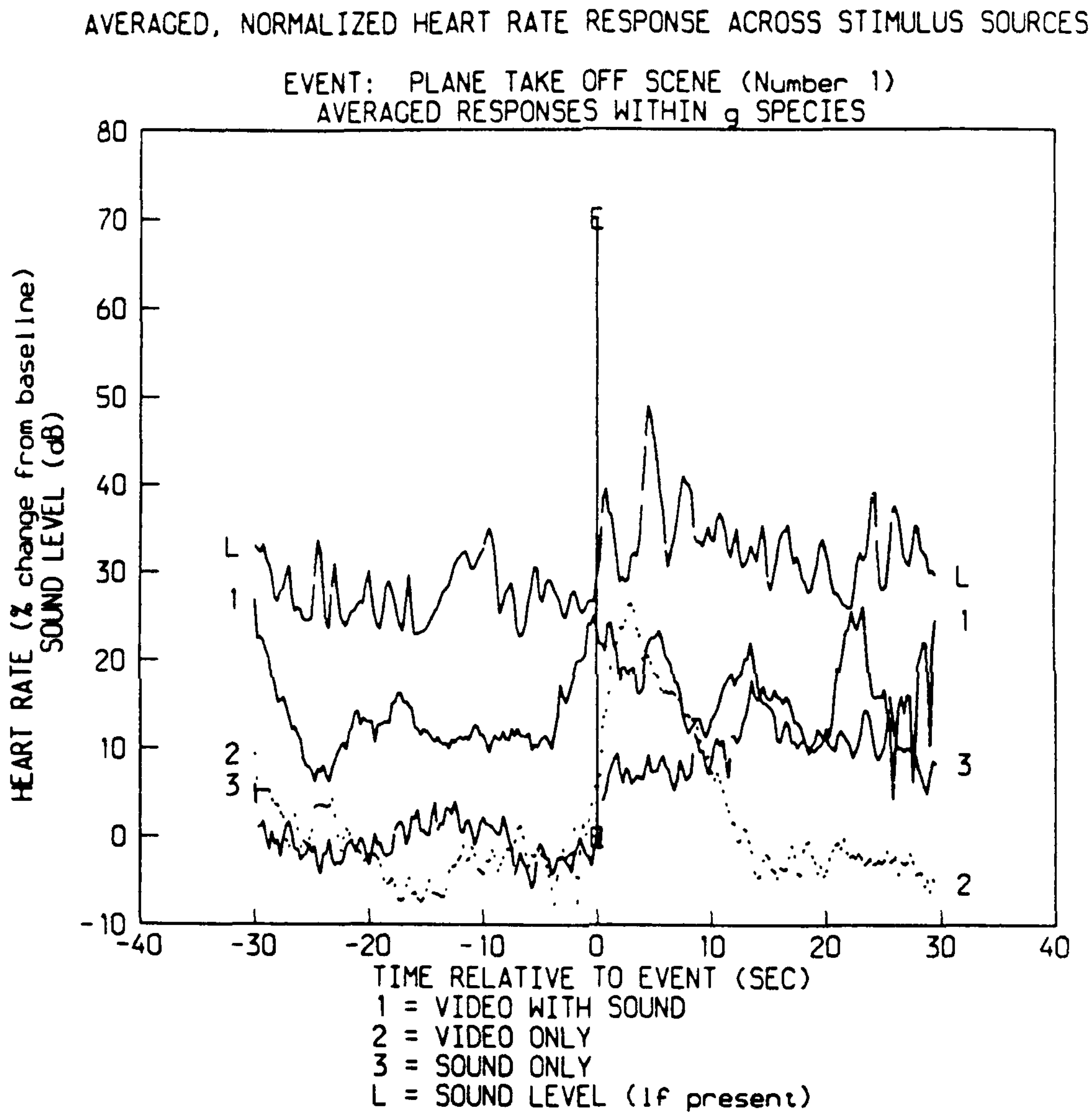


FIGURE 11. BOEING 737-300 (SCENE 1)

AVERAGED, NORMALIZED HEART RATE RESPONSE ACROSS STIMULUS SOURCES

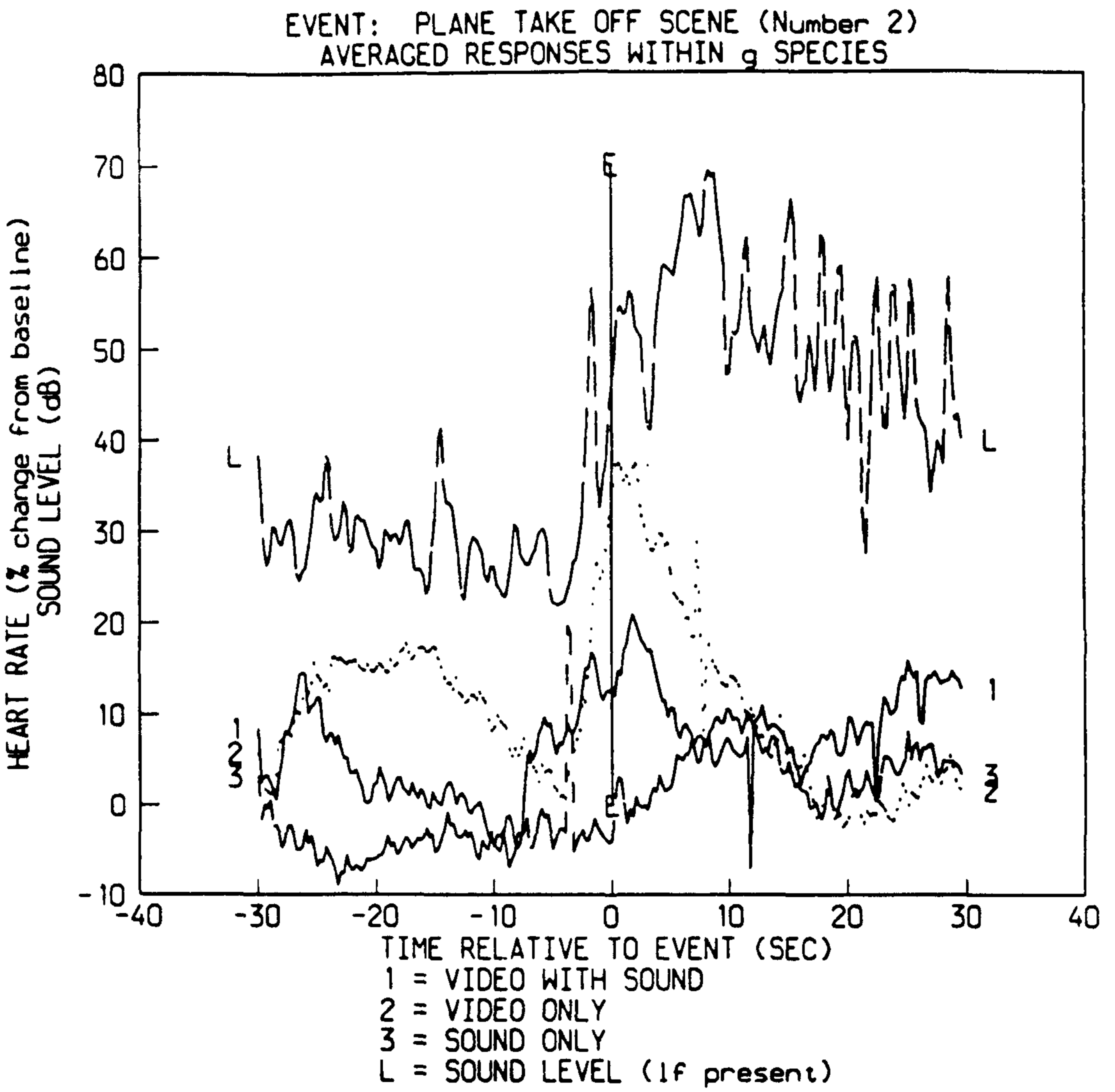


FIGURE 12. BOEING 737-200 (SCENE 2)

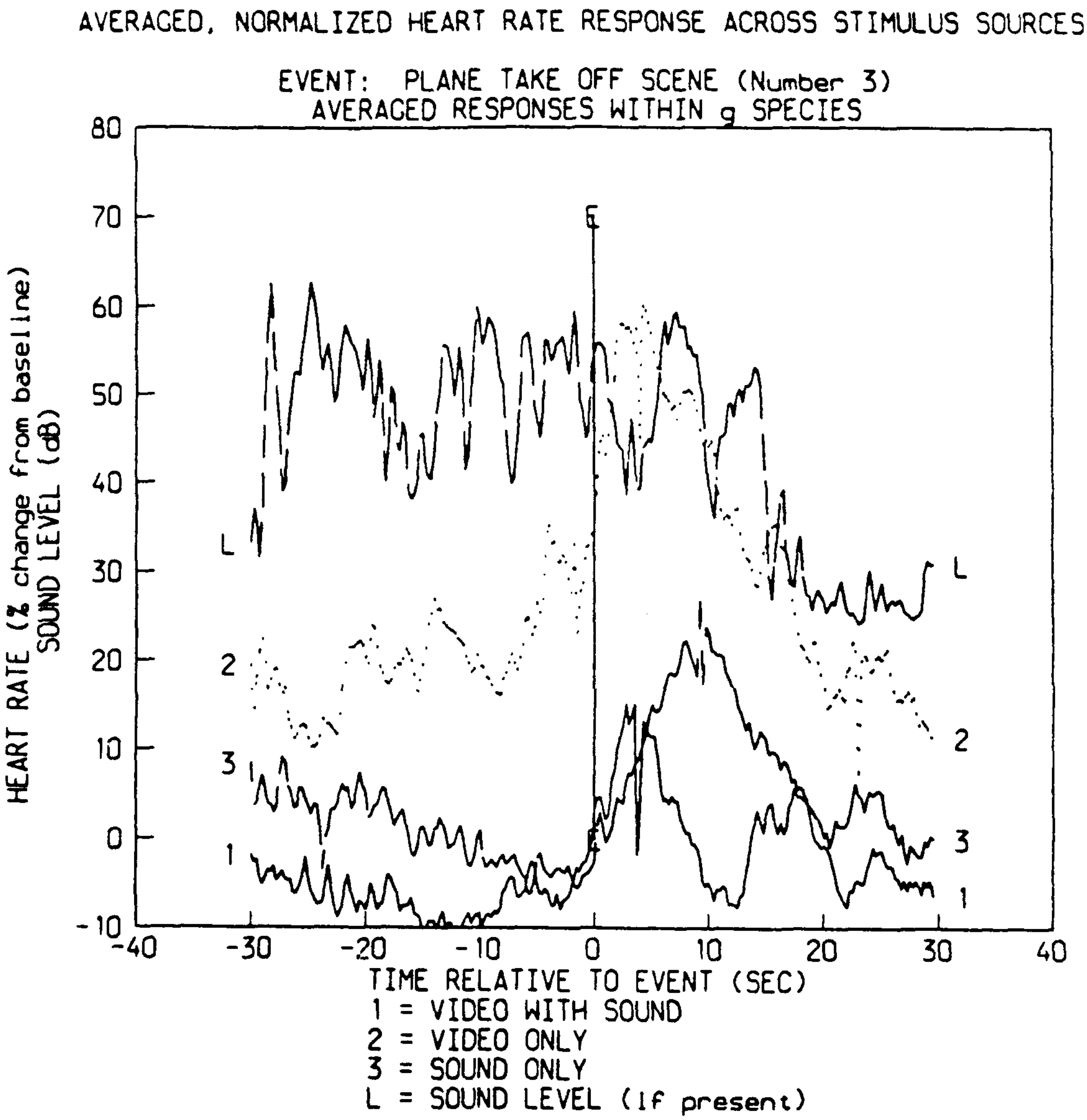


FIGURE 13. McDONNELL-DOUGLAS 80 (SCENE 3)

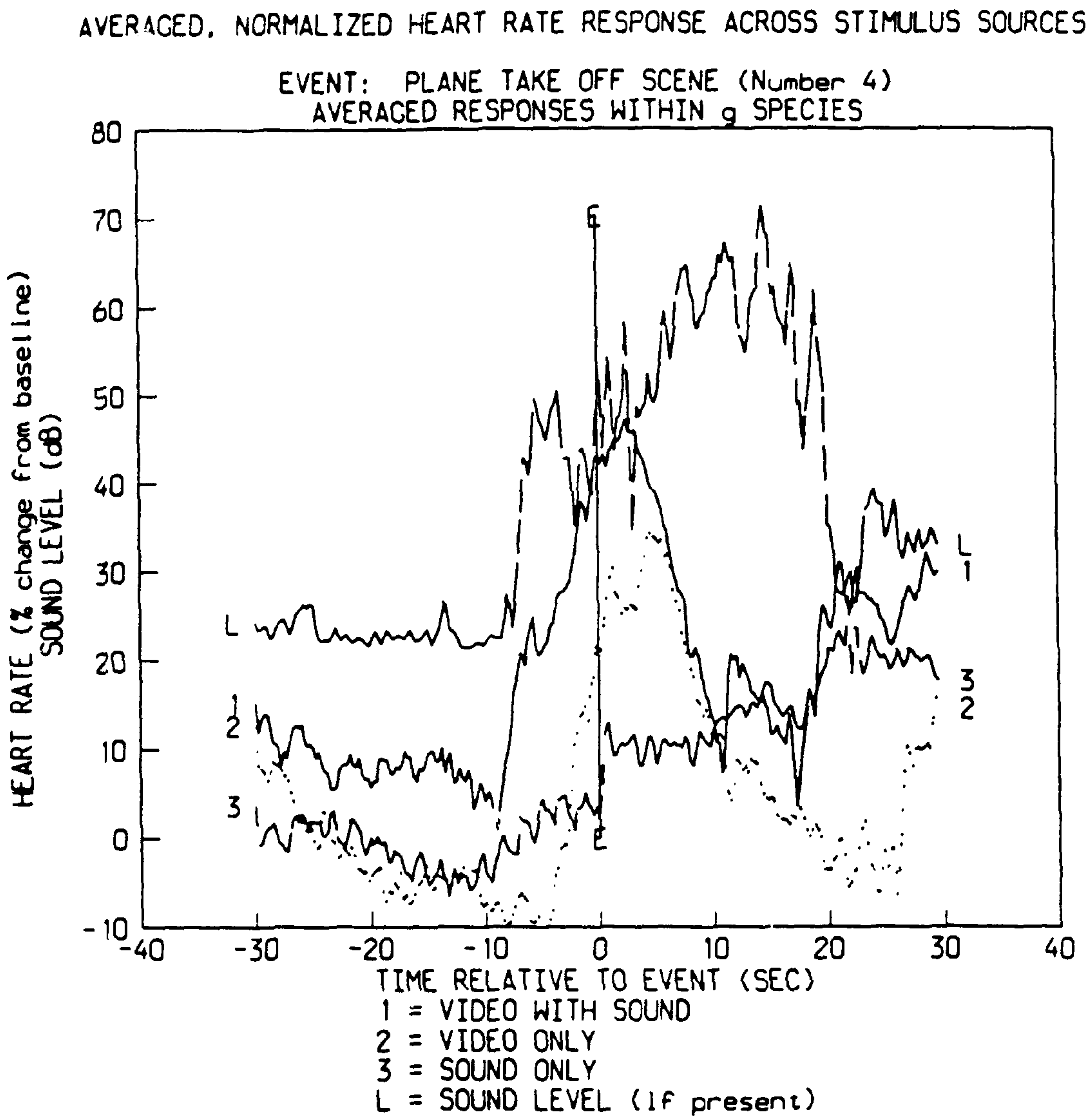


FIGURE 14. BOEING 727 (SCENE 4)

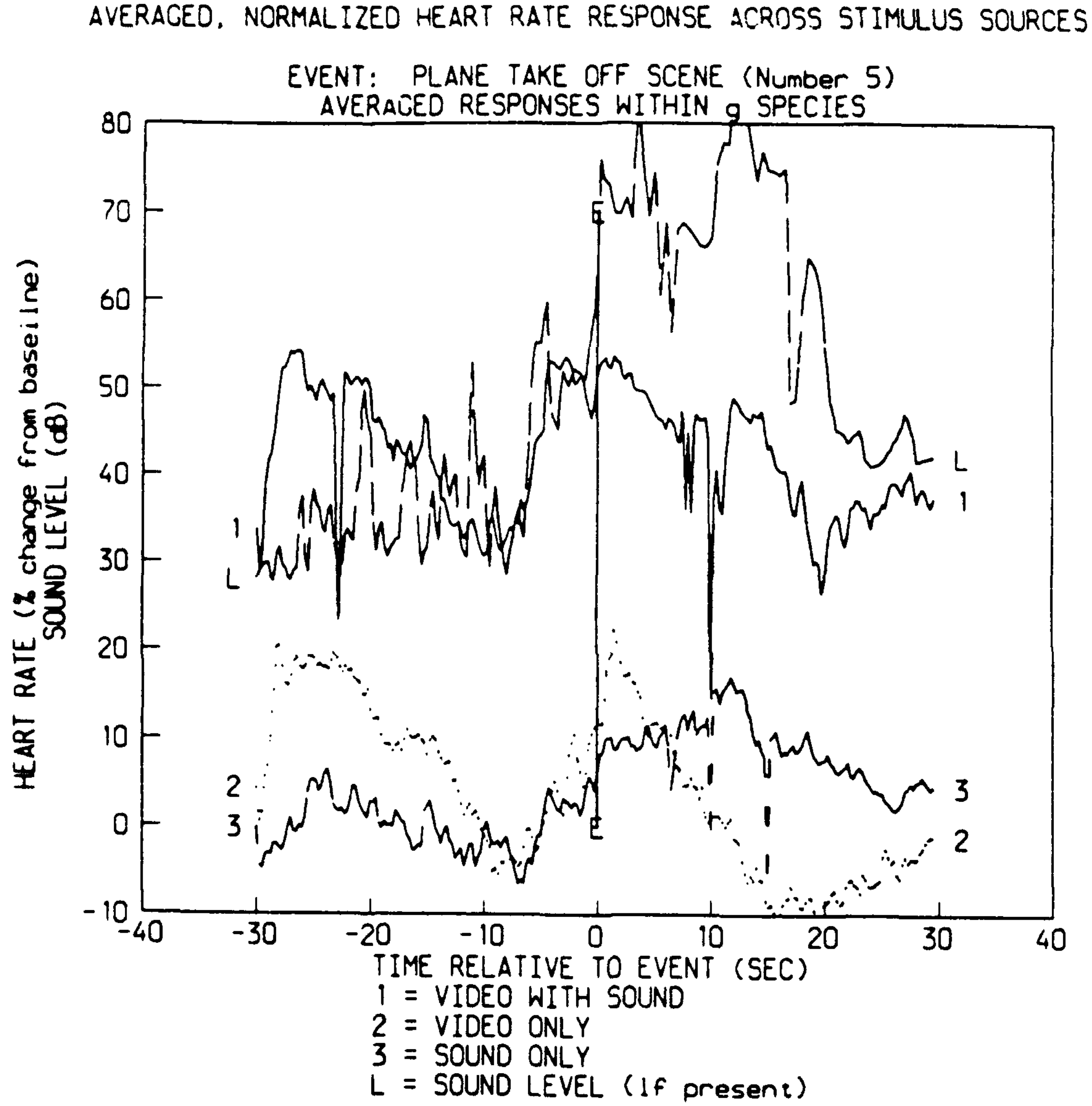


FIGURE 15. McDONNELL-DOUGLAS DC-9 (SCENE 5)

Figure 15 shows a DC-9 (Scene 5). The baselines on this graph are not well defined, but the heart rate response to the take-off stimuli occurred at the same time for all stimuli with the sight-only (video) returning to baseline quicker. The maximum heart rate response to the sound-only stimulus occurred about 12 seconds after the take-off.

Figure 16 shows a 727 (Scene 4). The heart and respiration rate of an unconditioned pigeon to the take-off scene was recorded on this graph. In order to show the respiration on the same graph, the respiration rate was multiplied by four. The heart rate started increasing several seconds before the respiration rate. The respiration and heart rate then followed a close-parallel relationship of about five heart beats to one breath.

Figures 17 through 19 show the normalized heart rate response of a conditioned bird (wild pigeon No. 6) to the video scene 2, which was a 737-200 during the take-off roll. This test was repeated three times (once per day for 3 consecutive days) to observe changes in the bird's response. The results of the repeat tests appeared to show a consistent response. Statistical reduction was not performed on this test.

STATISTICAL ANALYSIS OF HEART RATE RESPONSE OF BIRDS TO APPROACHING AIRCRAFT.

Experimental Design. The experimental design used in this study consisted of testing three gulls, four unconditioned (tame) pigeons and six conditioned (wild) pigeons. Three of the wild pigeons were each exposed to the film sequence three times in order to estimate the variability within a species of bird. Therefore, only the first testing sequence of these birds is included in the analysis outlined below.

Each test involved exposing the bird to a video which included five take-off sequences. In order to investigate the bird's response to different stimuli, i.e., sight and/or sound of approaching aircraft, the video was run three different times. Every test started with the video program including sight-and-sound. This test was followed by either a sight-only or sound-only test exposure video program. The sight-only and sound-only programs alternated from bird to bird.

In summary, 13 birds were tested with three different stimuli and five different film take-off sequences. Data were recorded for each bird 30 seconds before airplane take-off and 30 seconds after airplane take-off for each of the test runs.

Response Variables. Six response variables measured from the laboratory tests conducted on the gulls and pigeons employed in this study were identified to be analyzed statistically. Each of these variables represented varying concepts in determining the reaction of the birds to the approaching aircraft. For example, two of the response variables measured actual heart rate responses, two represented reactions compared to before or after aircraft take-off, and the final two assess parameters related to the time and length of the response.

The maximum heart rate during response interval of each bird to the aircraft take-off was identified for every test sequence. The maximum heart rate during each of these response intervals was identified.

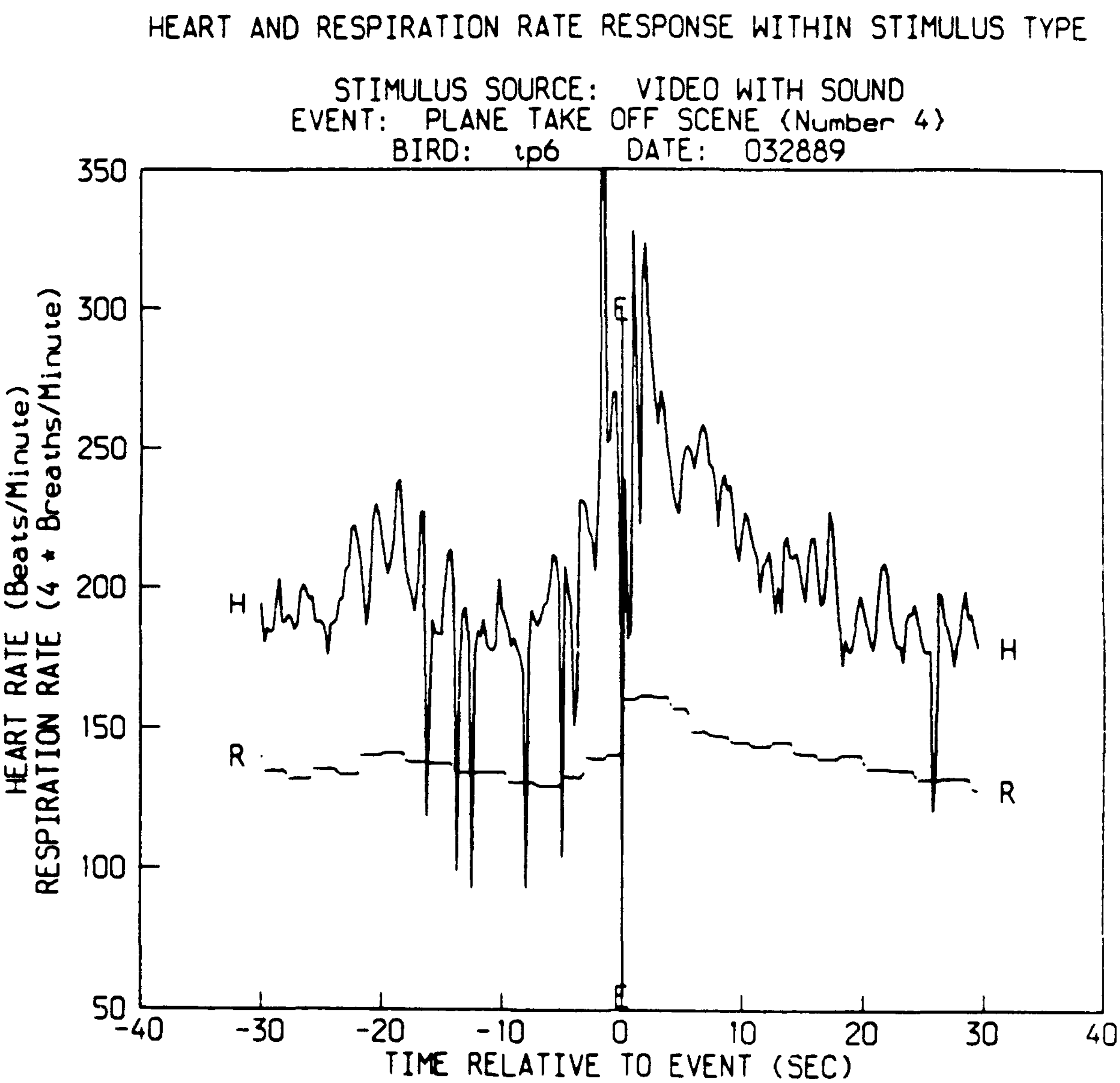


FIGURE 16. BOEING 727 (SCENE 4) (INCLUDES RESPIRATION RATE)

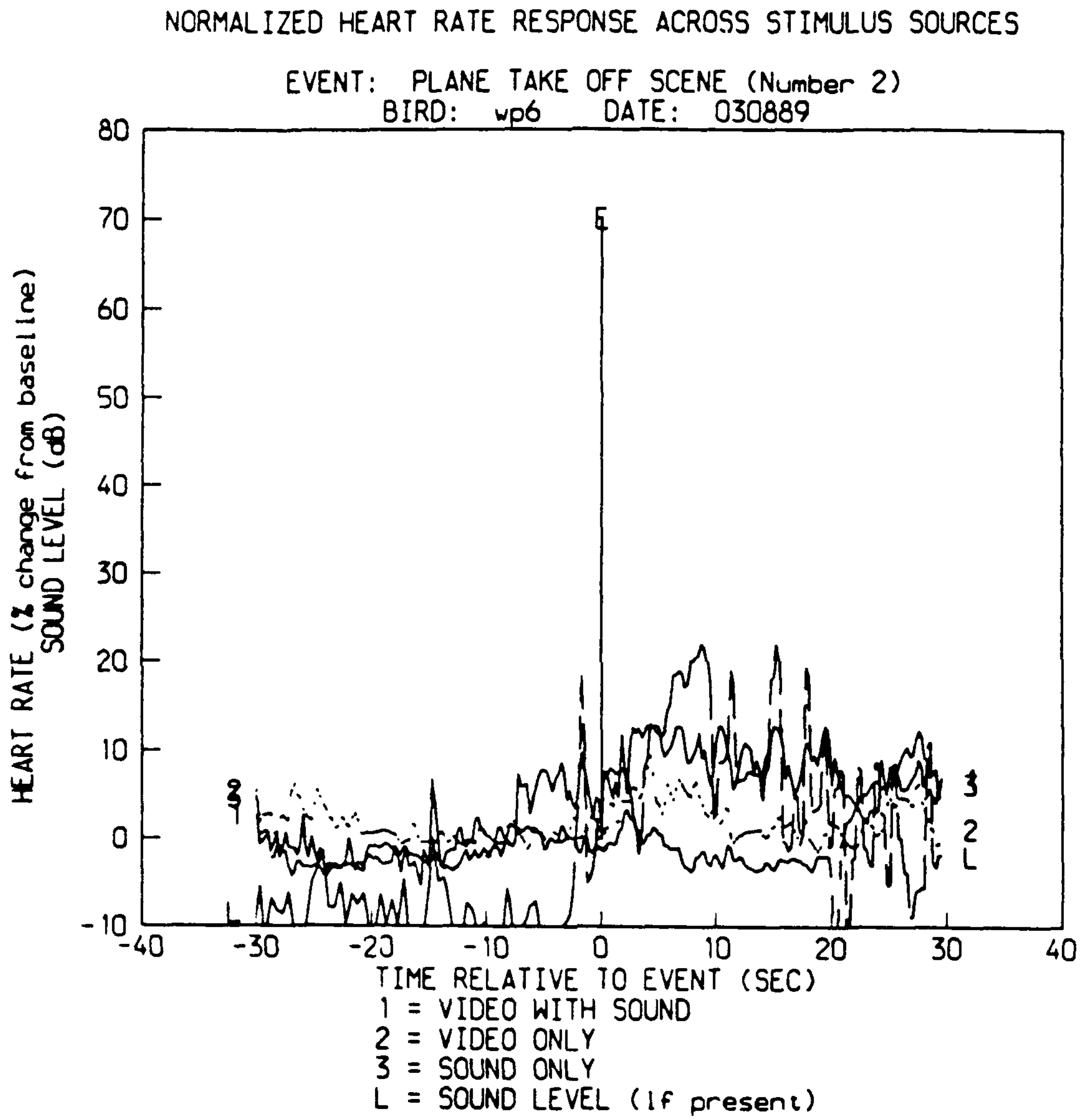


FIGURE 17. BOEING 737-200 (FIRST TEST)

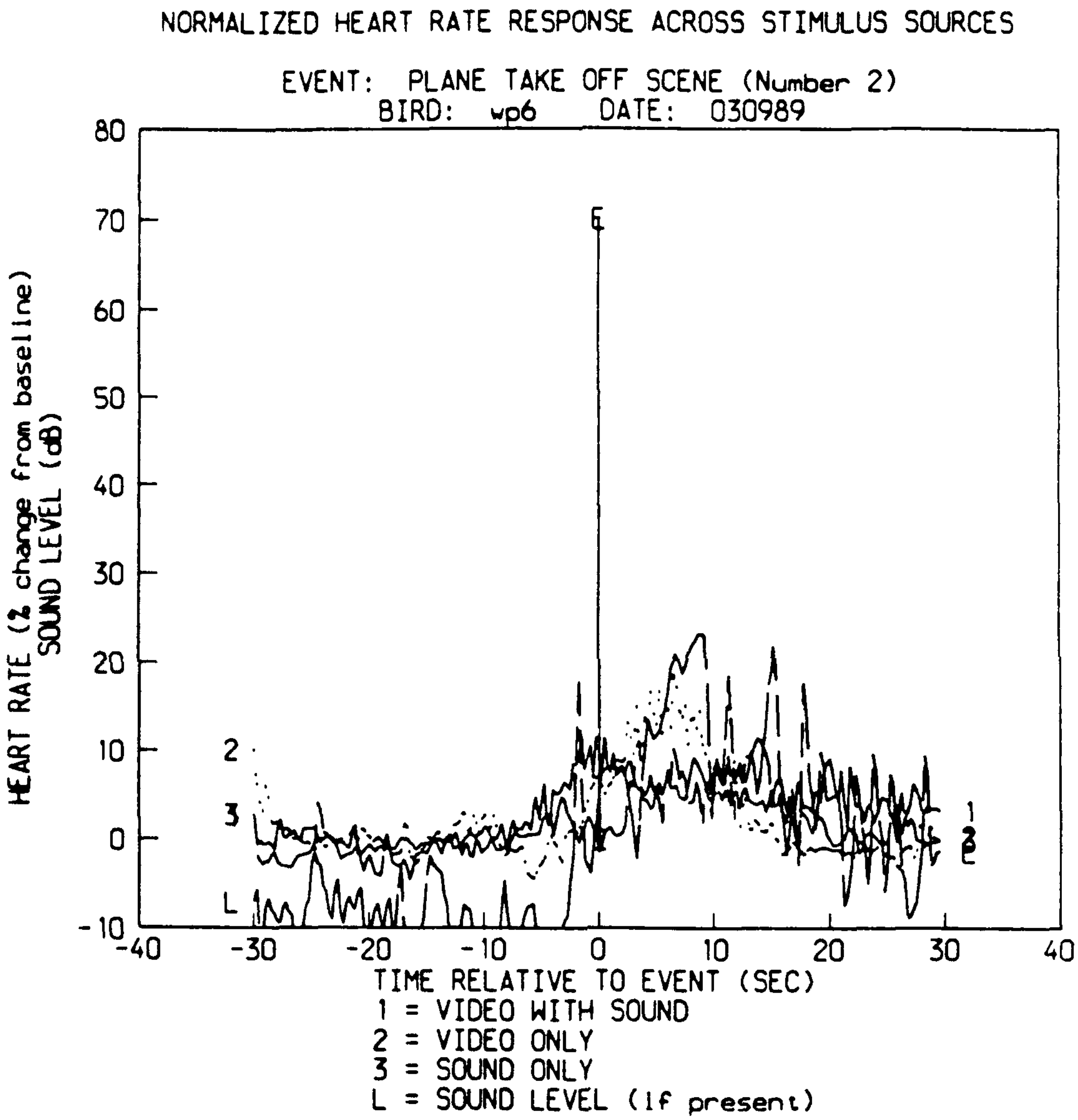


FIGURE 18. BOEING 737-200 (SECOND TEST)

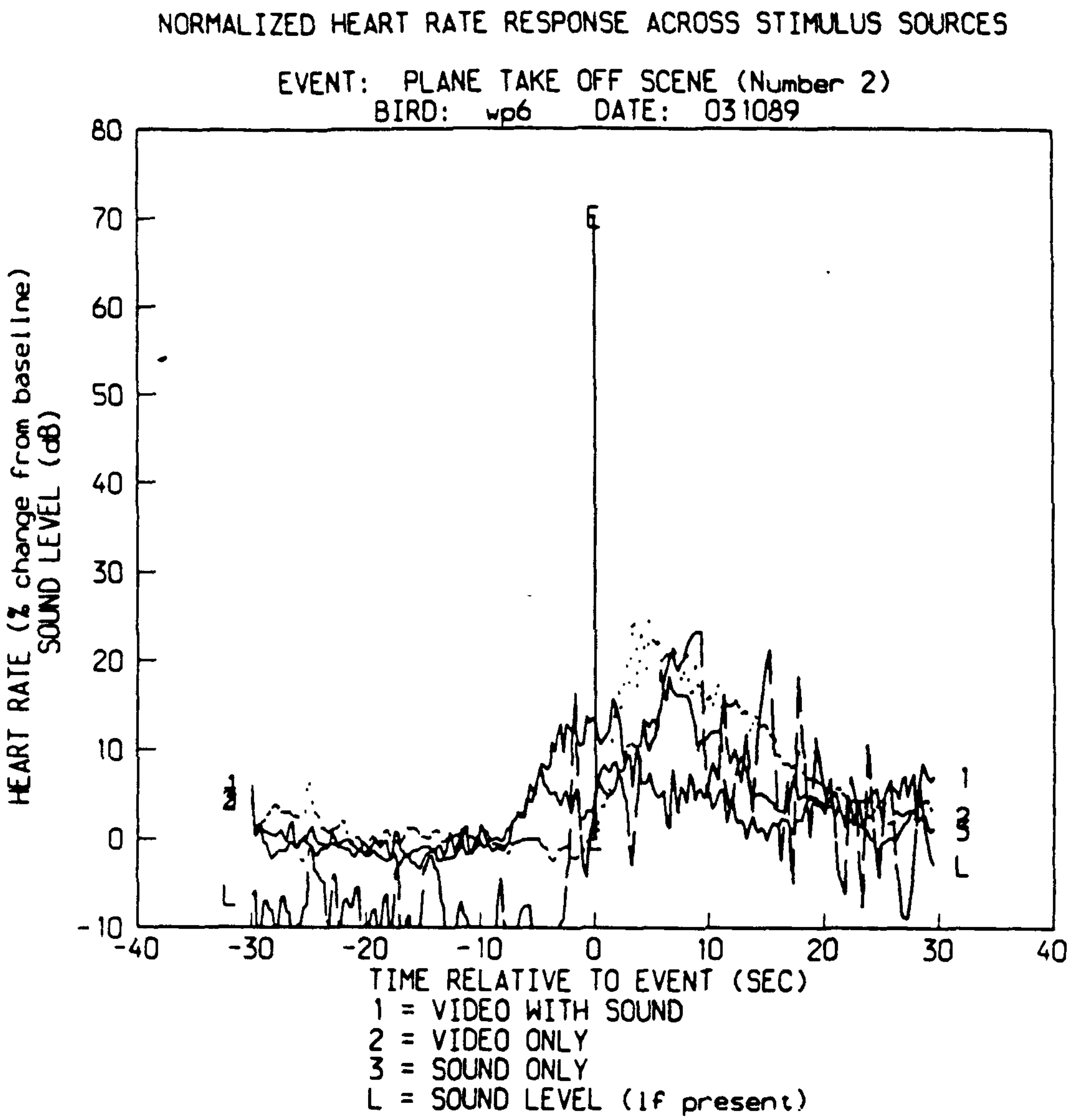


FIGURE 19. BOEING 737-200 (THIRD TEST)

The maximum heart rate during the bird's response interval was compared to the take-off of the aircraft. If the maximum heart rate occurred before take-off, a value of -1 was assigned to the location measure; a value of +1 was assigned to the location measure if the maximum occurred after take-off. If the maximum heart rate was coincident with the aircraft take-off, then a zero was assigned to the location measure.

An arithmetic average of the heart rate was computed for each bird during its response interval.

The beginning of the response interval (initial response) was identified with respect to the aircraft take-off. Values for this variable range from -30 seconds to +30 seconds. Negative values denote initial responses before take-off, whereas positive values denote initial responses after take-off. For example, a value of -5 represented an initial response 5 seconds before aircraft take-off.

The duration (seconds) of the bird's response to approaching aircraft was computed.

The time at which the bird made its initial response was compared to the take-off of the aircraft. If the initial response occurred before take-off, a value of -1 was assigned to the location measure. A value of +1 was assigned to the location measure if the initial response occurred after take-off. If the initial response was coincident with the aircraft take-off then a zero was assigned to the location measure.

STATISTICAL METHODOLOGY. Three independent variables (main effects or factors) were chosen in this study to investigate the effects, if any, they have on each of the six dependent (response) variables identified previously. These three main effects are bird type (gull, wild pigeon, and tame pigeon), film take-off sequence (1, 2, 3, 4, and 5) and stimuli (sight-and-sound, sight-only, and sound-only).

The statistical technique known as analysis of variance (ANOVA) (references 2,3,4) was used to determine whether significant differences exist among the means of groups of observations. This type of analysis was pertinent to this study in that it consisted of an examination and identification of the sources of variation present in the six response variables. The experimental design enabled the primary sources of variability to be defined and the amount of variability due to each of the three sources to be separated out of the total variability in the response data. Further, two-way interactions among the three main effects were also tested for statistical significance. The results from the appropriate ANOVA for each of the six response variables were given previously.

All the results from the ANOVAs were tested at the 0.10 percent level of significance. The assumptions of constant variance of the residuals, normality, and randomness needed in order to use the ANOVA techniques were met in all cases. If any main effects were found to be significant, additional tests were computed to determine which levels of the main effects produced average response values that were different from each other. These techniques are known as a multiple comparison test on means (references 5,6). The specific test used in this investigation was the Tukey-Dramer method, which is

useful when there are an unequal number of observations in the levels of the main effects.

STATISTICAL RESULTS. Each of the six response variables identified previously were analyzed using ANOVA techniques. The analysis which best describes the variation present in the response data is given below.

Maximum Heart Rate During Response Interval. An analysis of variance was performed which identified two significant main effects: BIRDTYPE and STIMULUS. The calculated p-values for BIRDTYPE and STIMULUS were both $p < 0.09$. All effects were tested at the 0.10 level of significance. Thus, the average of all the maximum heart rates measured during the bird's response interval was statistically different across the three types of birds and across the three different stimuli. Table 3 lists the average of the maximum heart rates by main effects.

TABLE 3. AVERAGE OF MAXIMUM HEART RATE.

Bird Type	Sample Size	Average
Gull	44	32.8
Tame Pigeon	60	49.3
Wild Pigeon	89	40.0
Stimulus	**Sample Size**	**Average**
Sight-only	65	32.8
Sound-only	63	47.2
Sight and sound	65	44.0

A multiple comparison test was used to distinguish which bird types generated maximum heart rates that were significantly different, on average, from the others. Tame pigeons showed significantly higher (0.10 percent level of significance) maximum heart rates than gulls. Wild pigeons were not significantly different, on the average, from either of the two groups.

All birds demonstrated a higher maximum heart rate, on average, to the sound-only stimulus than the sight-only stimulus. The sight-and-sound video produced no significant difference in the average maximum heart rate from the other two stimuli.

Location of Maximum Heart Rate Compared to Take-Off. ANOVA techniques were performed on the location of maximum heart rate as compared to take-off position. A significant interaction was found to exist among the levels of STIMULUS type and take-off SEQUENCE ($p < 0.0360$). Thus, STIMULUS and SEQUENCE have a significant joint effect on the average location of the maximum heart rate. The main effects cannot be tested with a significant interaction. Figure 20 illustrates how the average location of maximum heart rate changes between the sound-only stimulus and the sight-and-sound stimulus. Although statistical multiple comparison tests cannot be performed in this situation, one can see how the average location values are related to one another. For example, take-off sequence No. 1 shows a larger number of observations with a maximum heart rate occurring after the aircraft take-off for the sound-only

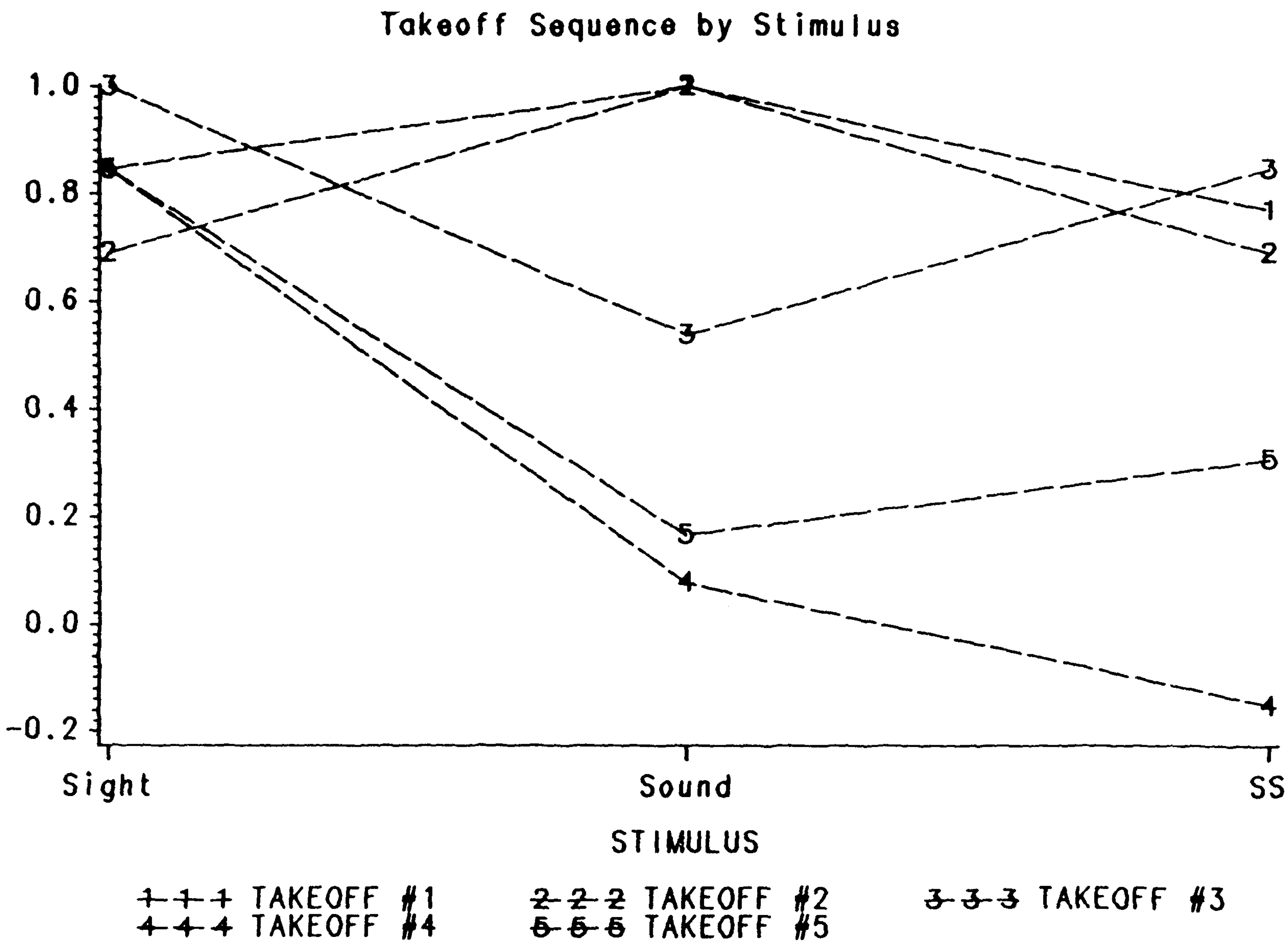


FIGURE 20. AVERAGE LOCATION OF MAXIMUM HEART RATE

stimulus than with the sight-and-sound stimulus. Table 4 represents the average location of the maximum heart rate by take-off sequence and stimulus.

Average Heart Rate in Response Interval. An analysis of variance was performed which identified three significant main effects: BIRDTYPE, SEQUENCE, and STIMULUS. The calculated p-values for BIRDTYPE, SEQUENCE, and STIMULUS are $p < 0.0068$, $p < 0.9293$, and $p < 0.0574$, respectively. All effects were tested at the 0.10 level of significance. Thus, the mean of the average heart rate during the response interval measured for each bird was statistically different across the three types of birds, the five different take-off sequences and the three types of stimuli. Table 5 lists the mean of the average heart rate during the response interval by main effects.

TABLE 4. AVERAGE LOCATION OF MAXIMUM HEART RATE.

Take-off	Stimulus	Sample size	Average
No.1	Sight	13	0.85
	Sound	13	1.00
	Sight and sound	13	0.77
No.2	Sight	13	0.69
	Sound	13	1.00
	Sight and sound	13	0.69
No.3	Sight	13	1.00
	Sound	13	0.54
	Sight and sound	13	0.85
No.4	Sight	13	0.85
	Sound	13	0.08
	Sight and sound	13	-0.15
No.5	Sight	13	0.85
	Sound	13	0.17
	Sight and sound	13	0.31

TABLE 5. MEAN OF AVERAGE HEART RATE IN RESPONSE INTERVAL

Bird Type	Sample Size	Average
Gull	44	17.4
Tame Pigeon	60	26.1
Wild Pigeon	89	35.9

Take-off	Sample size	Average
No. 1	39	17.0
No.2	39	27.6
No.3	39	27.3
No.4	39	34.7
No.5	37	36.9

Stimulus	Sample Size	Average
Sight-only	65	27.4
Sound-only	63	37.1
Sight and sound	65	21.6

A multiple comparison test was used to distinguish which bird types generated average heart rates that were significantly different on average from others. Gulls showed significantly lower (0.10 level of significance) average heart rates than the wild pigeons. Wild pigeons were not significantly different on average from tame pigeons with respect to average heart rates. All birds demonstrated a higher mean heart rate, on the average, to the sound-only stimulus than the sight-and-sound video. The sight-only stimulus was not significantly different from the other two stimuli.

There was a significantly higher mean heart rate on the average between sequences No. 5 and No. 1. There were no significant differences in the mean heart rates on the average between take-off sequences No. 2, No. 3, and No. 4.

<u>Time At Initial Response</u>. Statistical ANOVA calculations were executed on the time (in seconds) that the bird initially responded to the approaching aircraft. Two significant two-way interactions were found to exist among the levels of STIMULUS type by take-off SEQUENCE ($p < 0.0584$) and among the levels of STIMULUS type by BIRDTYPE ($p < 0.0049$). Thus, STIMULUS and SEQUENCE have a significant joint effect on the average time at the bird's initial response, as well as STIMULUS and BIRDTYPE. Because of the significant interaction, the main effects cannot be tested. Figure 21 illustrates how the average time at the initial response changed between the sound-only stimulus and the sight-and-sound stimulus when compared to the take-off sequences viewed by the birds. Although statistical multiple comparison tests cannot be performed in this situation, one can see how the average times at initial response are related to one another. For example, take-off sequence No. 4 shows an average time at initial response closer to the aircraft take-off for the sight-only stimulus than with the sound-only or sight-and-sound stimulus. Table 6 represents the average time at initial response by take-off sequence and stimulus.

TABLE 6. AVERAGE TIME AT INITIAL RESPONSE-TAKE-OFF SEQUENCE BY STIMULUS

Take-off	Stimulus	Sample size	Average
No.1	Sight	13	-1.27
	Sound	13	2.27
	Sight and sound	13	-0.92
No.2	Sight	13	-1.04
	Sound	13	-0.90
	Sight and sound	13	-3.96
No.3	Sight	13	-5.63
	Sound	13	-2.46
	Sight and sound	13	-4.35
No.4	Sight	13	-1.40
	Sound	13	-4.17
	Sight and sound	13	-6.75
No.5	Sight	13	-3.87
	Sound	13	-2.33
	Sight and sound	13	-3.54

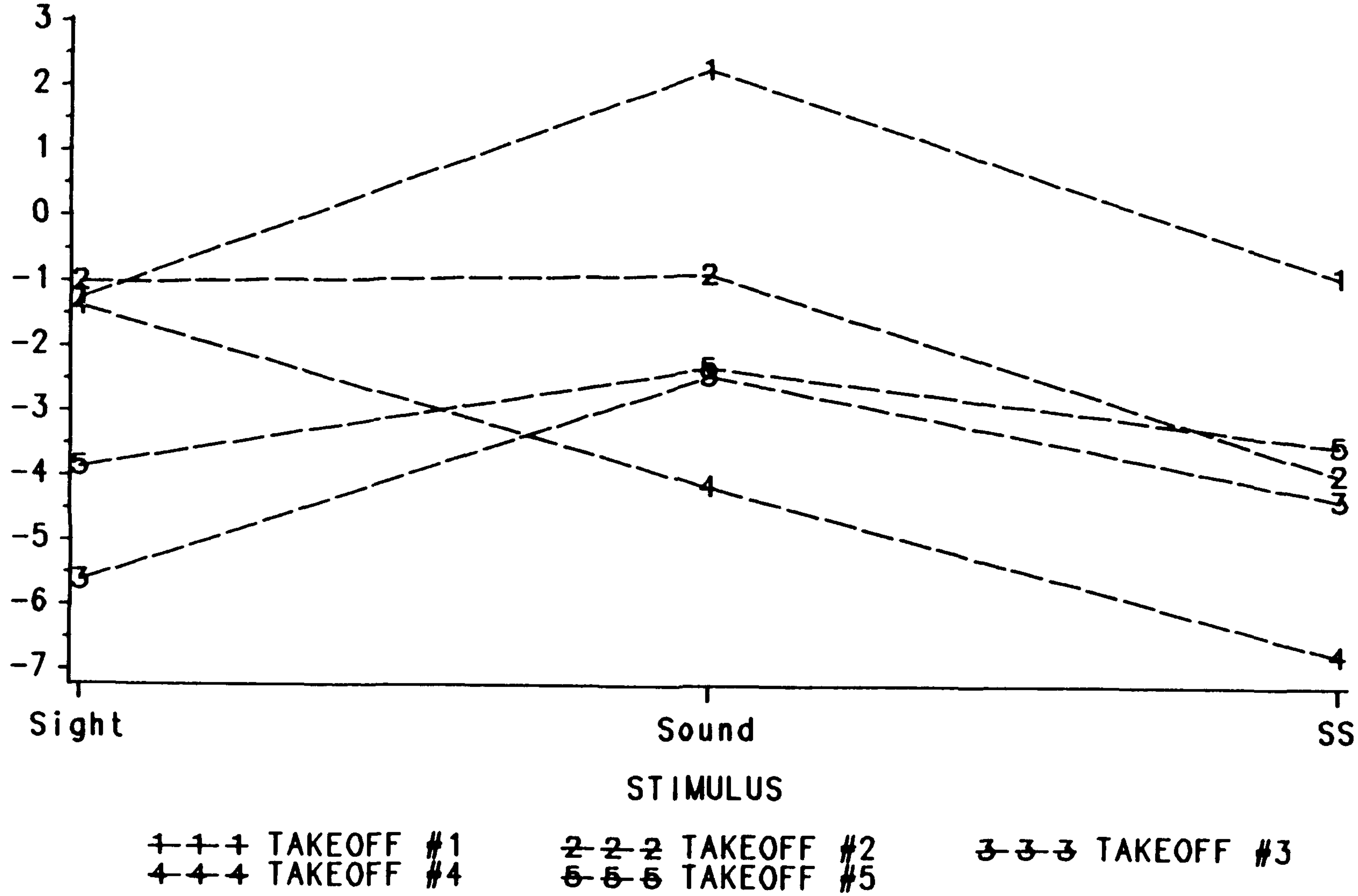


FIGURE 21. AVERAGE TIME AT INITIAL RESPONSE; TAKE-OFF SEQUENCE BY STIMULUS

Comparatively, figure 22 illustrates how the average time at the initial response changes between the sound-only stimulus and the sight-and-sound stimulus when compared to the different bird types. Although statistical multiple comparison tests cannot be performed in this situation, one can see how the average times at initial response are related to one another. For example, the gull shows an average time at initial response occurring after the aircraft take-off for the sound-only stimulus compared to responses before take-off for the sight-only or sight-and-sound stimulus. Table 7 represents the average time at initial response by take-off sequence and stimulus.

Length of Response Interval. An analysis of variance was performed which identified two significant main effects: BIRDTYPE and SEQUENCE. The calculated p-values for BIRDTYPE and SEQUENCE are both $p < 0.0001$. All effects were tested at the 0.10 level of significance. Thus, the average duration of the response interval measured by each bird was statistically different across the three types of birds and across the five different take-off sequences. Table 8 lists the average of the lengths of the response interval by main effects.

A multiple comparison test was used to distinguish which bird types generated response interval lengths that were significantly different on average from others. Gulls showed significantly longer (0.10 level of significance) response intervals than the tame pigeons with respect to average response interval durations.

All birds demonstrated a longer response interval on average to take-off sequence No. 3 than the other four sequences. Also, there was a significant difference in the duration of the response interval between sequences No. 5 and No. 1. There were no significant differences in the length of the response interval on average between take-off sequences No. 2, No. 4, and No. 5.

Location of Initial Response Compared to Take-Off. Statistical ANOVA calculations were executed on the location of the bird's initial response to the approaching aircraft as compared to the aircraft take-off. These results are the same as those discussed previously. Two significant two-way interactions were found to exist among the levels of STIMULUS type by take-off SEQUENCE ($p < 0.0735$) and among the levels of STIMULUS type by BIRDTYPE ($p < 0.0014$). Thus STIMULUS and SEQUENCE have a significant joint effect on the average location of the bird's initial response, as well as STIMULUS and BIRDTYPE. Because of the significant interaction, the main effects cannot be tested. Figure 23 illustrates how the average location of the initial response changes between the sight-only stimulus and the sound-only stimulus when compared to the take-off sequences viewed by the birds. Although statistical multiple comparison tests cannot be performed in this situation, one can see how the average locations of initial response are related to one another. For example, take-off sequence No. 1 shows that, on average, more birds responded initially to the approaching aircraft before take-off for the sight-only stimulus than for the sound-only stimulus. Table 9 represents the average location of initial response by take-off sequence and stimulus.

Figure 24 illustrates how the average location of initial response changes between the sound-only stimulus and the sight-and-sound stimulus when compared to the different bird types. Again, statistical multiple comparison

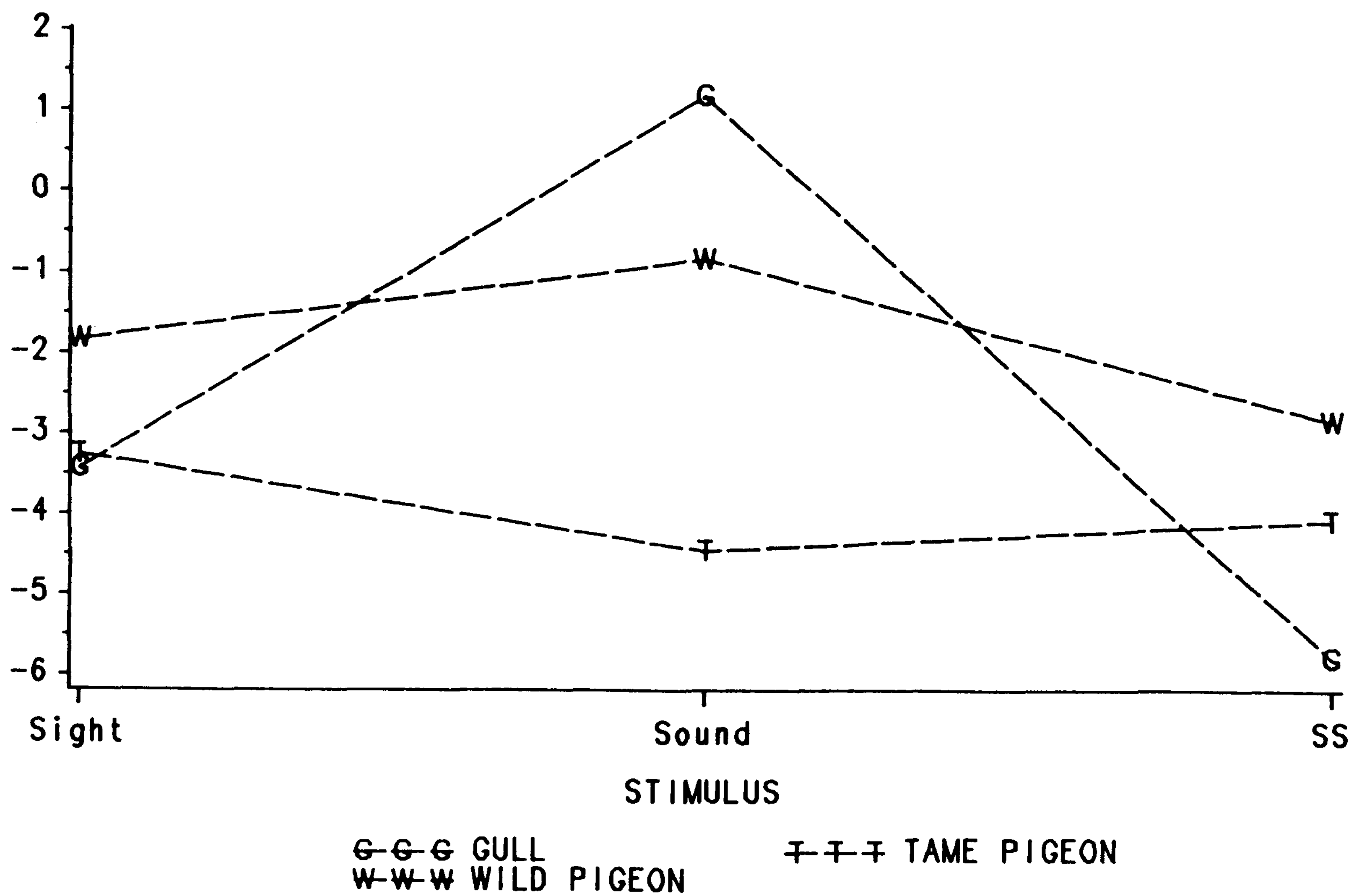


FIGURE 22. AVERAGE TIME AT INITIAL RESPONSE; BIRD TYPE BY STIMULUS

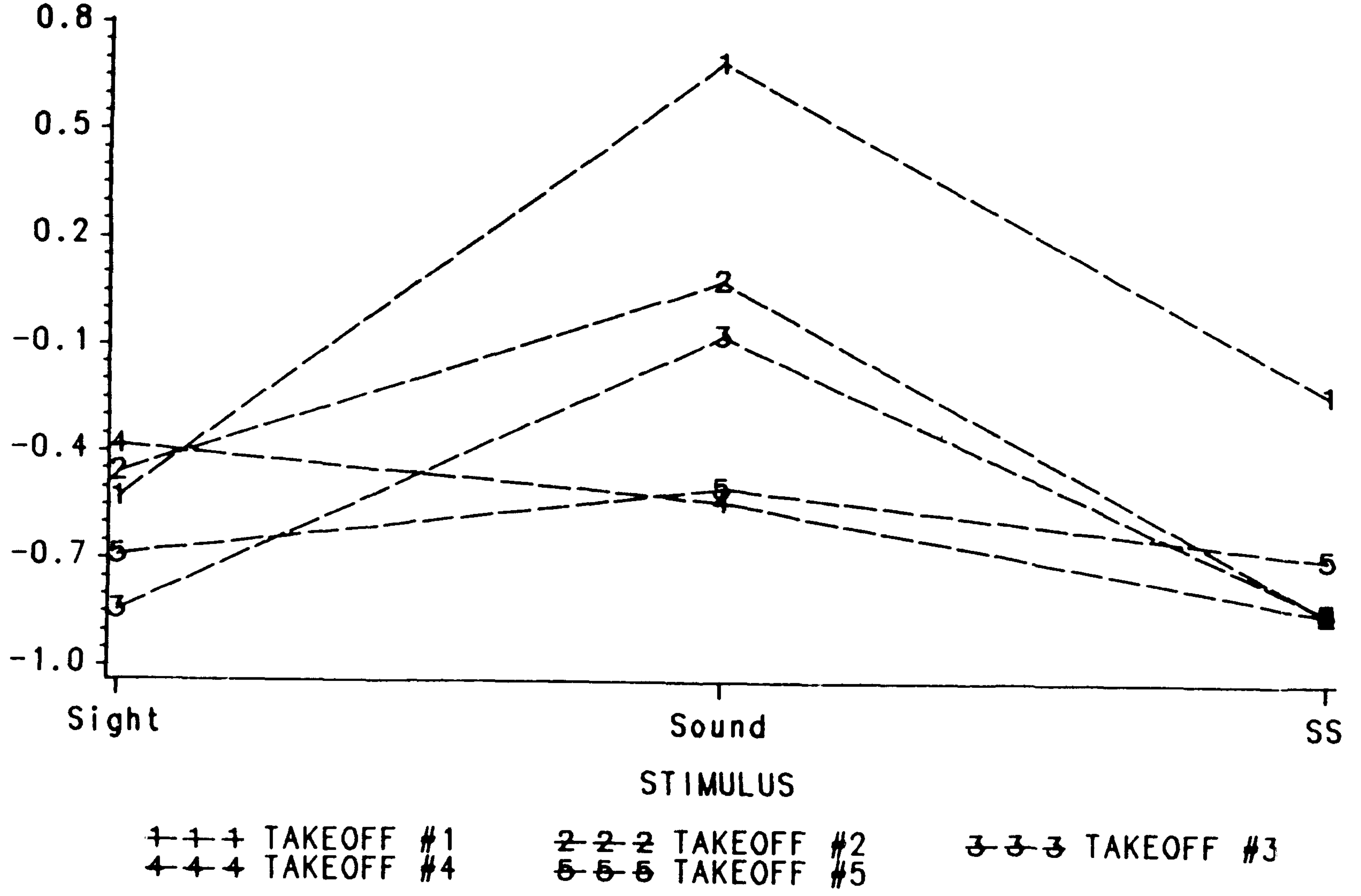


FIGURE 23. AVERAGE LOCATION OF INITIAL RESPONSE; TAKE-OFF SEQUENCE BY STIMULUS

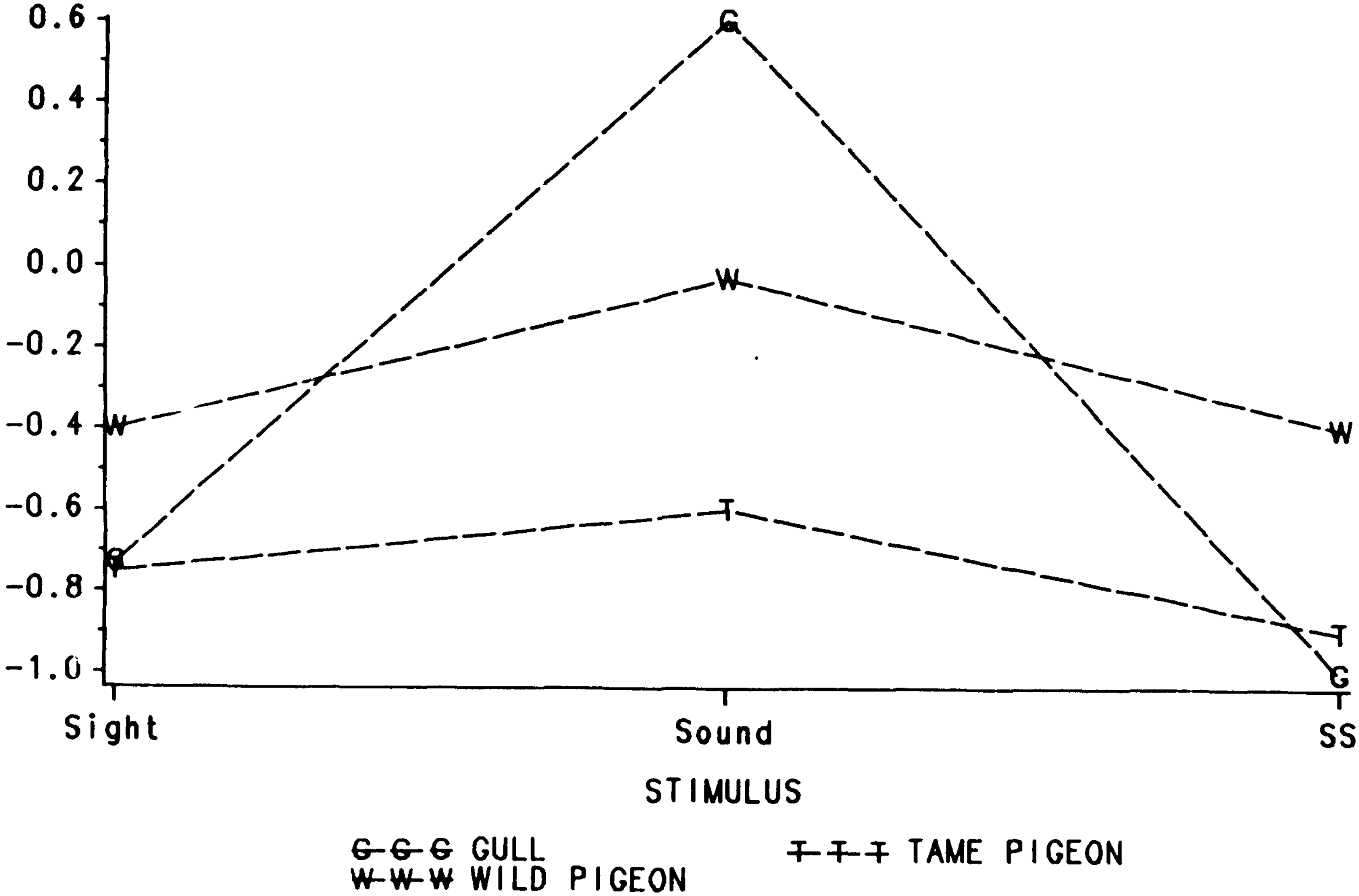


FIGURE 24. AVERAGE LOCATION INITIAL RESPONSE; BIRD TYPE BY STIMULUS

TABLE 7. AVERAGE TIME AT INITIAL RESPONSE - BIRD TYPE BY STIMULUS

Bird Type	Stimulus	Sample size	Average
Gull	Sight	15	-3.43
	Sound	15	1.17
	Sight and sound	15	-5.77
Tame Pigeon	Sight	20	-3.26
	Sound	20	-4.46
	Sight and sound	20	-4.08
Wild Pigeon	Sight	30	-1.83
	Sound	29	-0.85
	Sight and sound	30	-2.86

TABLE 8. AVERGE OF LENGTH OF THE RESPONSE INTERVAL

Bird Type	Sample Size	Average
Gull	44	32.8
Tame Pigeon	60	49.3
Wild Pigeon	89	40.0

Take-off	Sample size	Average
No.1	39	10.8
No.2	39	13.5
No.3	39	17.3
No.4	39	14.0
No.5	37	14.4

TABLE 9. AVERAGE LOCATION OF INITIAL RESPONSE-TAKE-OFF SEQUENCE BY STIMULUS

Take-off	Stimulus	Sample size	Average
No.1	Sight	13	-0.54
	Sound	13	0.69
	Sight and sound	13	-0.23
No.2	Sight	13	-0.46
	Sound	13	-0.08
	Sight and sound	13	-0.85
No.3	Sight	13	-0.85
	Sound	13	-0.08
	Sight and sound	13	-0.85
No.4	Sight	13	-0.38
	Sound	13	-0.54
	Sight and sound	13	-0.85
No.5	Sight	13	-0.69
	Sound	13	-0.50
	Sight and sound	13	-0.69

tests cannot be performed in this analysis. However, one can see how the average locations of initial response are related to one another. Considering gulls, for example, more birds were tested in which the initial response occurred after the aircraft take-off for the sound-only stimulus than with the sight-only or sight-and-sound stimulus. Table 10 represents the average time at initial response by take-off sequence and stimulus.

TABLE 10. AVERAGE LOCATION OF INITIAL RESPONSE-BIRD TYPE BY STIMULUS

Bird Type	Stimulus	Sample size	Average
Gull	Sight	15	-0.73
	Sound	15	0.60
	Sight and sound	15	-1.00
Tame Pigeon	Sight	20	-0.75
	Sound	20	-0.60
	Sight and sound	20	-0.90
Wild Pigeon	Sight	30	-0.40
	Sound	29	-0.03
	Sight and sound	30	-0.40

CONCLUSIONS.

Data analysis indicated the conditioned birds that were captured near an active runway showed less response to an approaching aircraft during the take-off roll. For early detection of approaching aircraft, the conditioned birds (wild pigeons and gulls) appeared to use sight-only and sight-and-sound as their first stimulus response. The tame pigeons behaved as if the intensity of the sound of the approaching aircraft was the strongest stimulus. This supports the evidence that wild birds conditioned to the sight-and-sound of the aircraft are sometimes not stimulated by fright in time to escape approaching aircraft. The bird does not have time to move away from danger if the sound-only was a stimulus because most of the sound occurred after the aircraft had passed the bird. The approaching sound of the aircraft was against a variable wind speed of 10 to 15 miles per hour (mph) on the day of taping the video.

The greatest distance of the location of the camera (bird view) to the rotation point of the aircraft was in scene 1. The sight was the first indicator, followed by sight-and-sound. The aircraft was off the ground before the sound stimulated a response.

Scene 2 showed that the sight-and-sound was the earliest indicator, then sight and (at rotation) the sound became a stimulus. In scene 3, where the bird had a view along the runway to the start of the take-off roll and watched the aircraft approaching with lights in full view, the sight with sound and sight-only both became the earliest indicators. At this close, head-on approach of the aircraft, the sound did not become an indicator until right at the rotation point.

Scene 4 was the same distance from the edge of the runway as scenes 1, 2, and 3. The sight-and-sound was the earliest indicator, then sound, and then sight. All indicators of danger were present before the aircraft passed the bird's view.

Scene 5 was similar to scene 4 (all three stimuli caused a response), but was closer to the aircraft rotation point; all three stimuli caused responses at about the same time.

Sampling across bird species and between species indicates the gull and pigeon both use sight-and-sound and sight-only as the earliest indicators; sound-only was not an early indicator, as the aircraft had rotated before the sound bothered the gull. The tame pigeon seemed to respond early to all three stimuli; it was not accustomed to the aircraft or runway noises.

The wild pigeon used all three stimuli as indicators, but was very late in responding to danger because of the conditioned behavior to aircraft and runway scenes.

DISCUSSION.

The Phase I laboratory experiment showed that the model birds (pigeons and gulls) can detect and will react to a video scene of an aircraft during the take-off roll. The methods used constituted a satisfactory process to obtain certain physiological data in an actual field study, with the exception of usable respiration data. In order to obtain the respiration and heart rate of the test birds in the laboratory study, a direct wire (five-lead) physiograph was used. The direct wiring method restricted the normal movement of the bird, and in one test, the bird removed all five leads in one violent motion. Another disadvantage with the direct wire method was the difficulty in accurately attaching the five leads to a conscious bird without causing harm. The bird respiration data were eliminated from the Phase II field data, and the ECG transmitter was used on the test bird.

PHASE II--TASK I--FIELD TEST
DATA COLLECTION OF HEART RATE RESPONSE OF BIRDS

EXPERIMENTAL SETUP.

The experimental setup at the San Antonio International Airport is shown in figure 25. The birdcages (figure 26) were lined up to allow the test birds (three gulls and three pigeons) an open view of the approaching aircraft on the active runway. The accelerometer for monitoring ground vibration and the sound level meter (figure 27) were placed beside the bird test cages. The birdcage receivers, accelerometer, and sound level meter were attached to the mobile laboratory monitoring equipment by a 250-foot cable (figure 28). A safety chain (figure 29) connected all equipment adjacent to the runway to prevent movement in the event of air turbulence from passing aircraft. Sandbags were also used to anchor equipment.

The electric power required for the equipment was supplied by an 8-kilowatt (kW) generator (figure 30) mounted on the mobile laboratory. Heating and cooling of the laboratory were supplied by a roof-mounted unit.

The mobile laboratory contained an 8-channel strip chart recorder (figure 31); one channel for each of the six test birds, and one channel each for the accelerometer and the sound level meter. The analog signals of the bird's heart rate from the bird cage receivers on each channel were processed by a Gould Biotech, presented on the chart recorder, and recorded on tape recorders. A 14-channel Racal magnetic tape recorder (figure 32) was used. A self-contained portable tape recorder was also used in the field laboratory monitoring system.

The recording tape was returned to SwRI Department of Biosciences and Bioengineering for storage and statistical analysis on the Masscomp computer.

BIRDS.

The test birds (12 pigeons and 12 gulls) were identified by leg band numbers and were housed at the SwRI aviary area (figure 33).

The birds (figure 34) were randomly selected and assigned to test groups (three of each species for each test). A harness was placed on the pigeons 4 hours prior to the test for harness acclimation. The birds were fitted with harness and transmitter (figure 35) 1 1/2 hours before testing. The gulls were fitted with a styrofoam and Velcro™ hood over the eyes to keep the birds quiet during transportation from SwRI to the San Antonio International Airport. A ventilated cover box was also placed over each birdcage during transport. The cover box had one side closed and was used during the sound-only experiment to block the bird's vision. These precautions were taken to keep the feral birds from physical damage in the test cage.

The test cage (figure 36) was constructed of vinyl-dipped, 16-gauge wire and measured 30.48 x 40.64 x 30.48 cm (12 x 16 x 12 inches). The transmitter receiver (figure 29) was mounted in the top of each cage. A power supply and signal cable were connected to each receiver. All cages, wires, and equipment were color-coded for accuracy of connections.

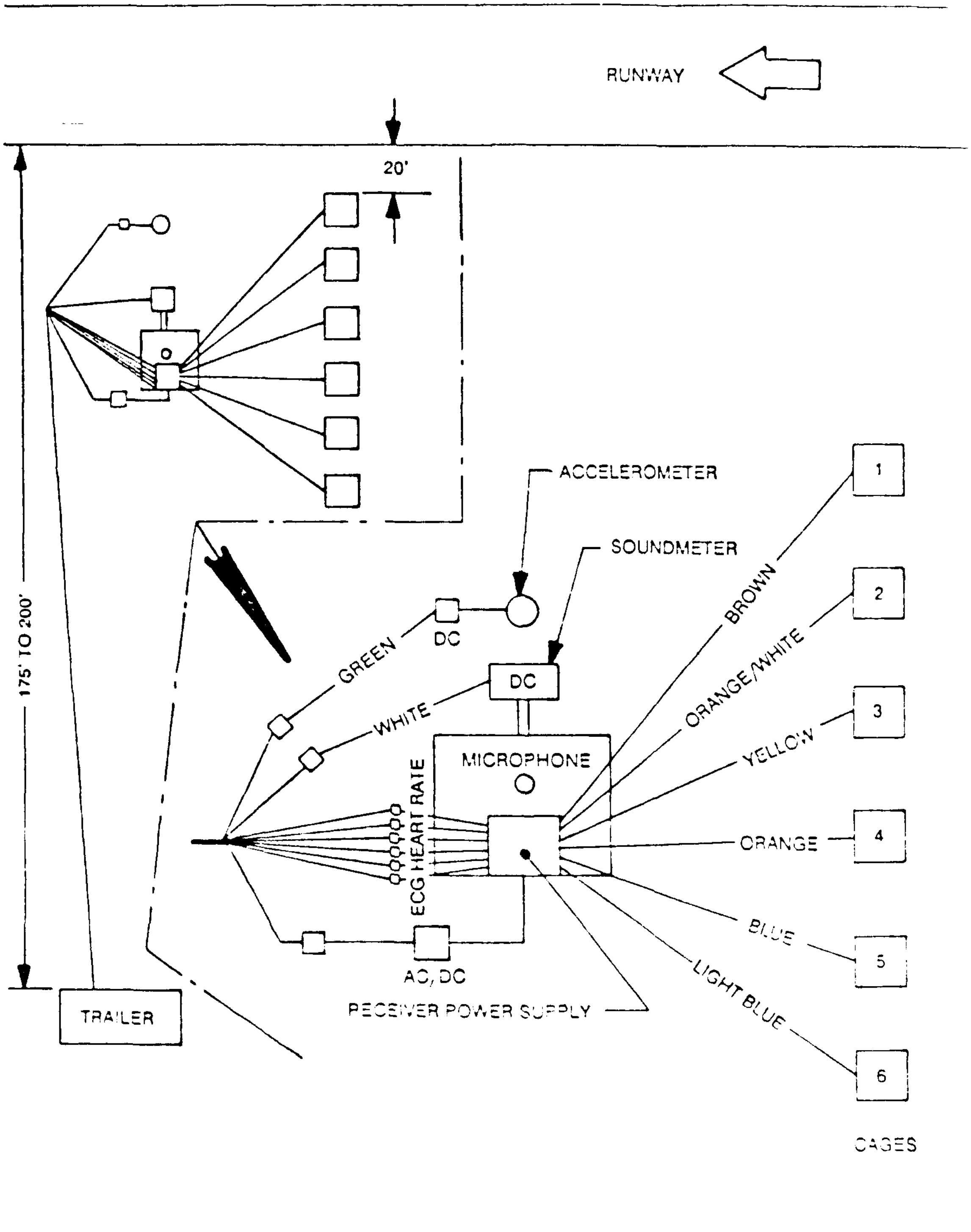


FIGURE 25. EXPERIMENTAL SETUP WITH TEST BIRDS NEAR AN ACTIVE RUNWAY AT THE SAN ANTONIO INTERNATIONAL AIRPORT

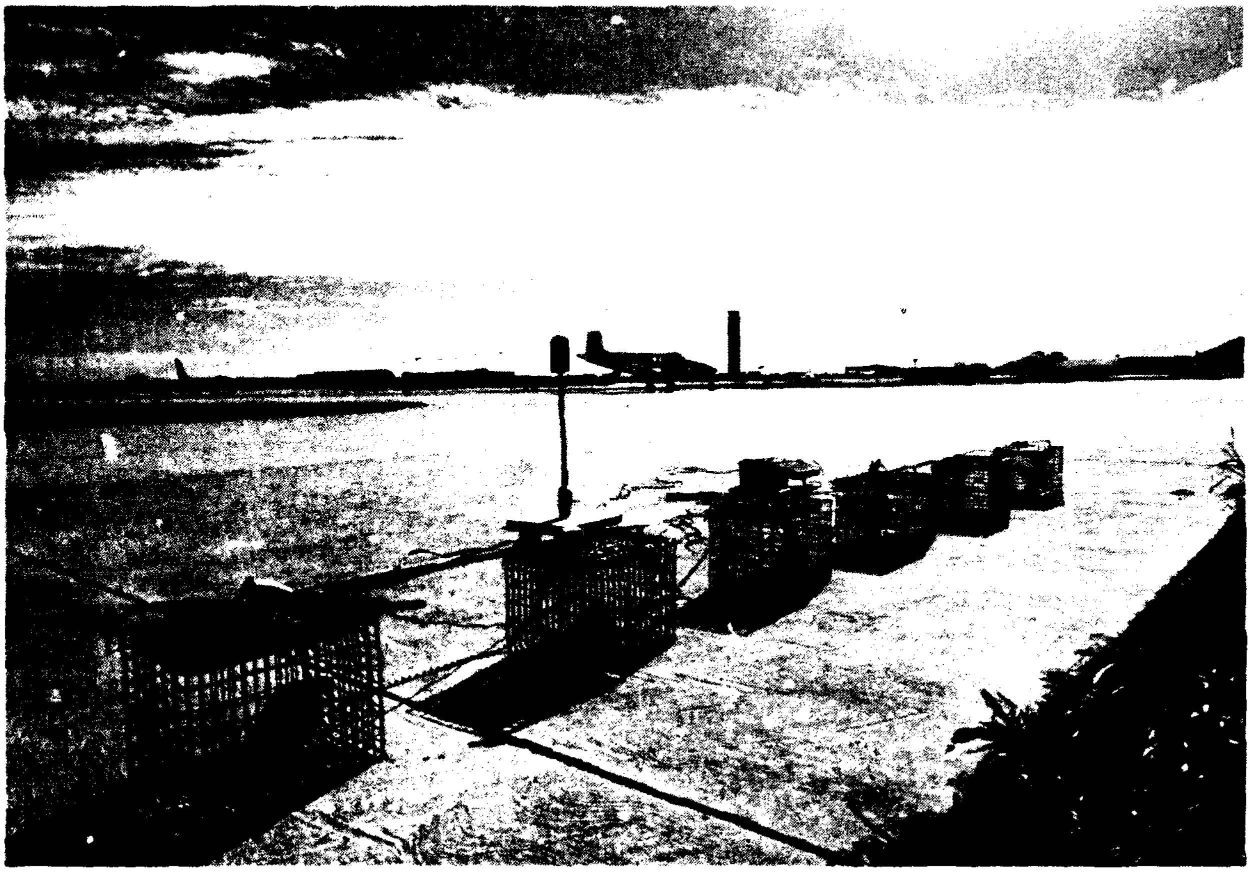


FIGURE 26. EXPERIMENTAL SETUP ON TAXIWAY "ALPHA" ADJACENT TO ACTIVE RUNWAY 12R

FIGURE 27. EXPERIMENTAL SETUP SHOWING SOUND LEVEL METER, MICROPHONE, AND ACCELEROMETER

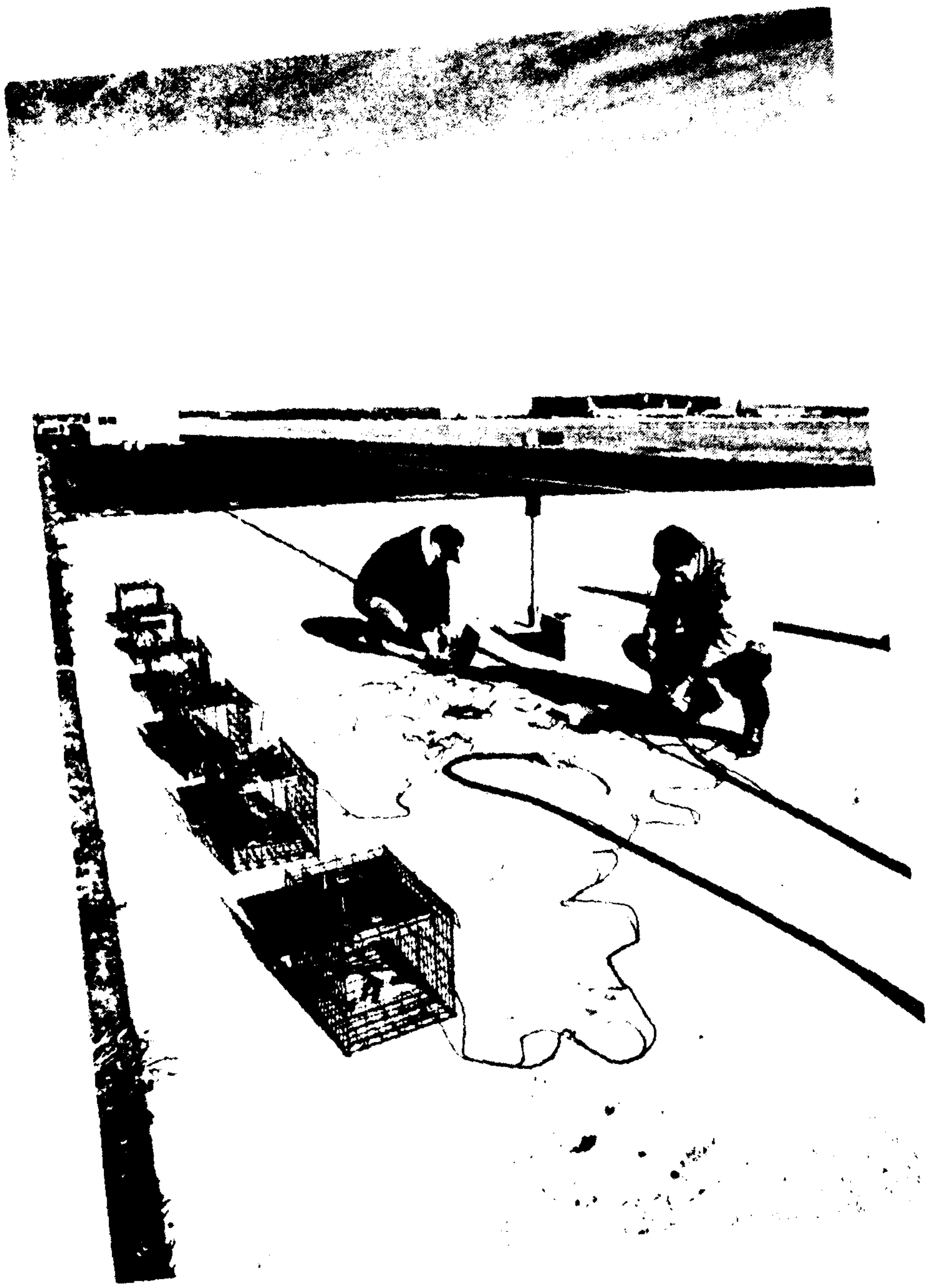


FIGURE 28. CONNECTION OF EXPERIMENTAL EQUIPMENT AND TEST CAGES TO CABLES FROM MOBILE LABORATORY

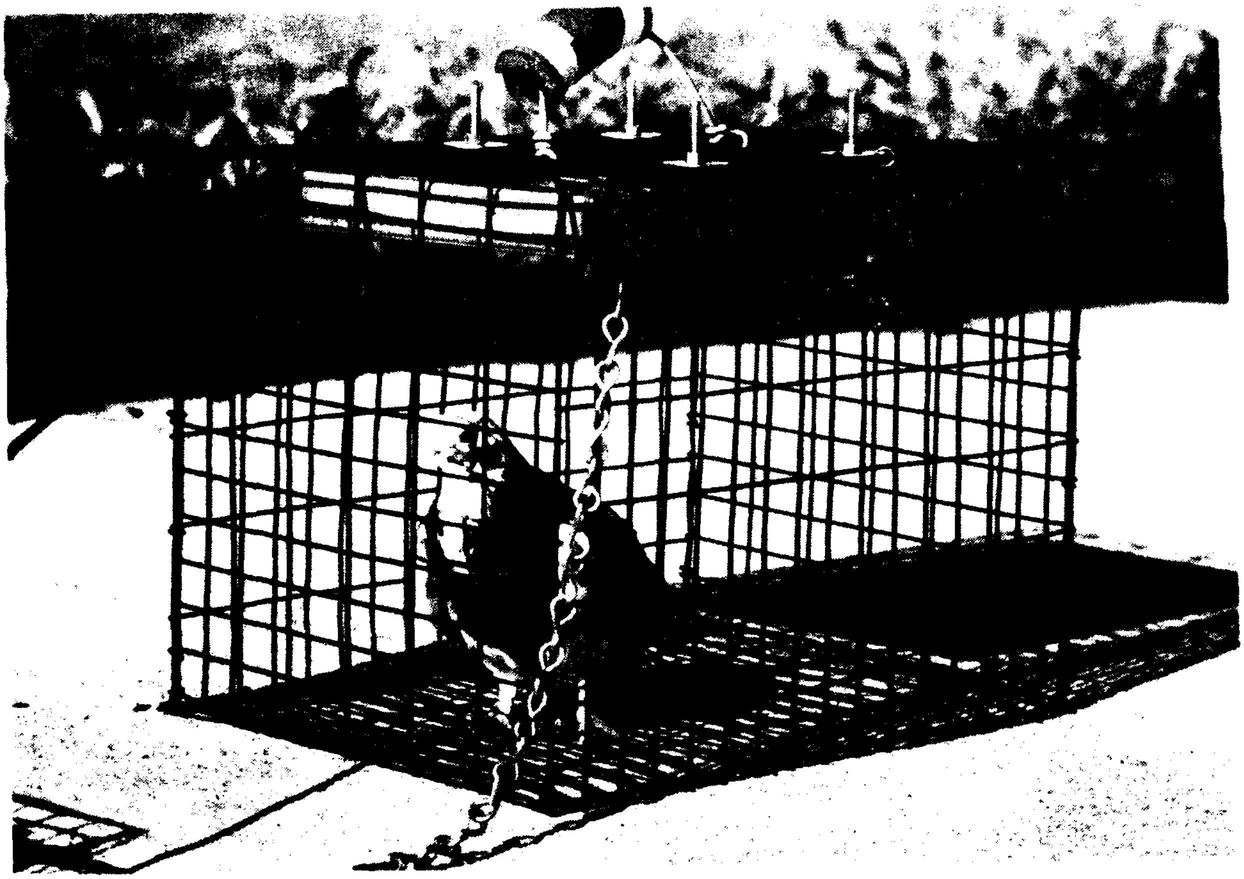


FIGURE 29. INDIVIDUAL BIRD TEST CAGE SHOWING DETAILS OF CAGE WITH SAFETY CHAIN

FIGURE 30. ELECTRIC POWER FOR THE MOBILE LABORATORY TRAILER SUPPLIED BY AN 8kW GENERATOR

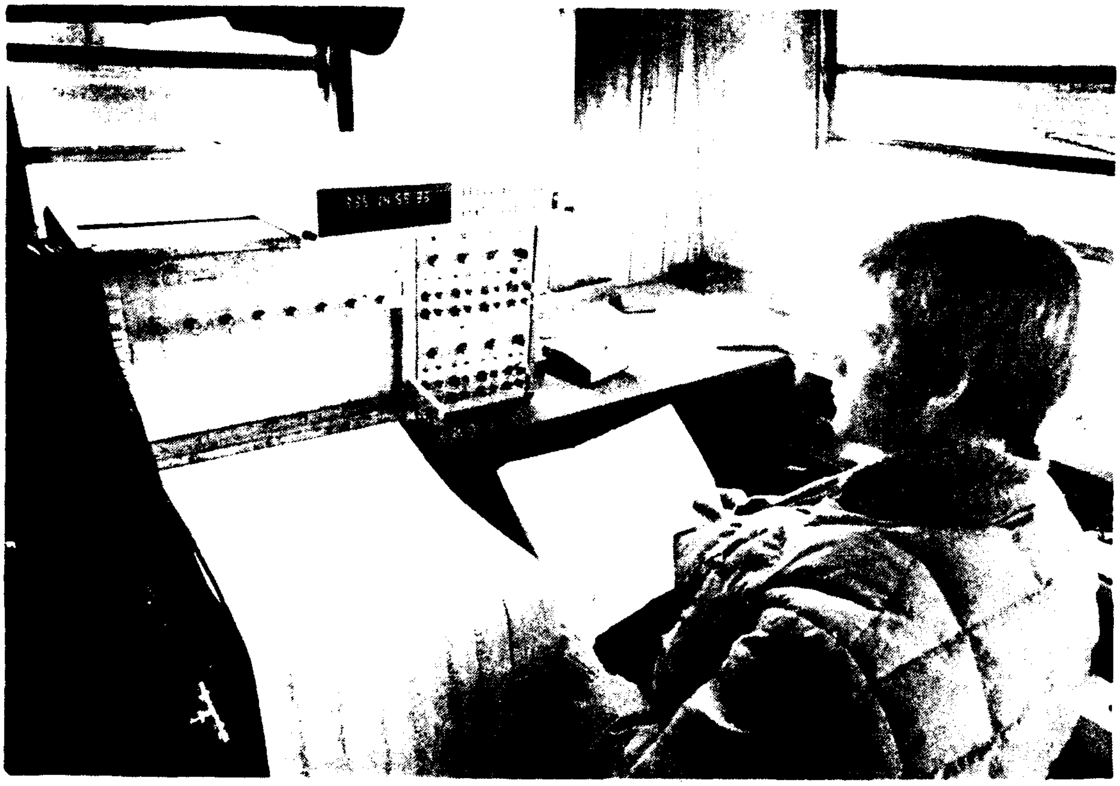


FIGURE 31. MOBILE LABORATORY EQUIPMENT -- AN 8-CHANNEL STRIP CHART RECORDER, TIME CODE GENERATOR, AND EVENT MARKER

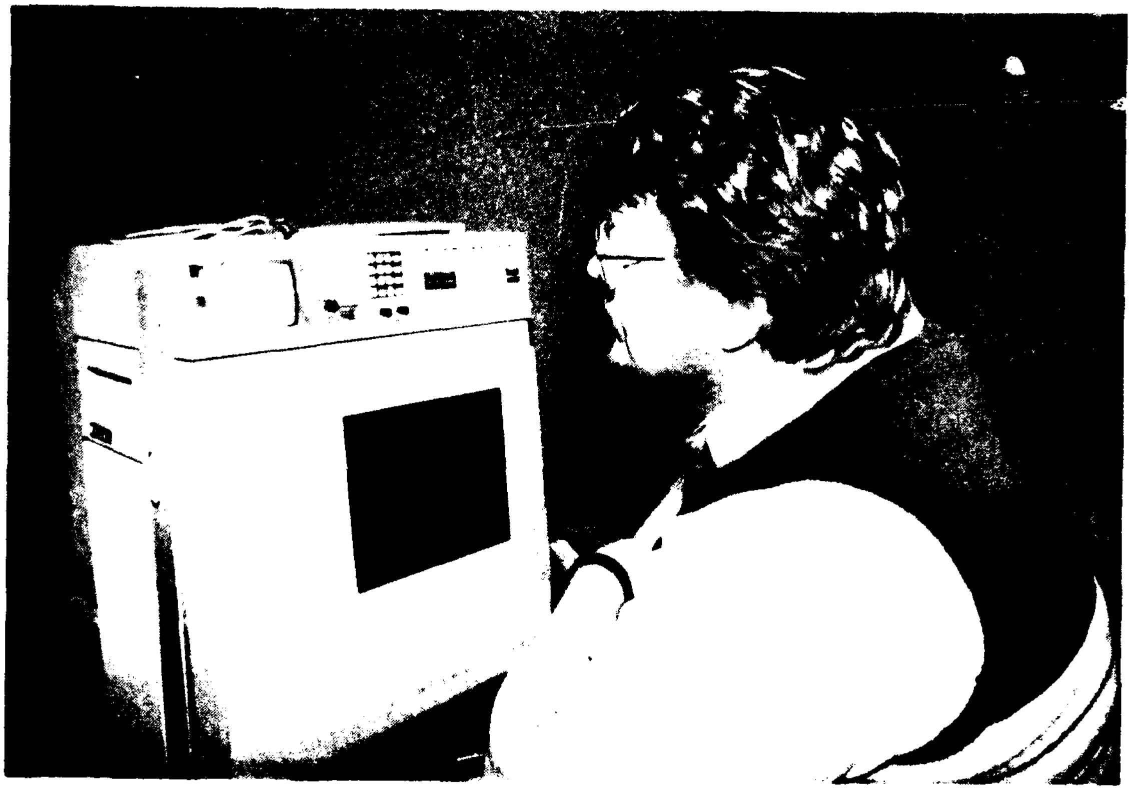


FIGURE 32. A 14-CHANNEL RACAL MAGNETIC TAPE RECORDER USED TO STORE TEST EQUIPMENT SIGNALS

FIGURE 33. GULLS IN SWRI WITH LEG BAND IDENTIFICATION. SUMMER PHOTOGRAPH SHOWING DARK HEAD COLOR OF GULL

FIGURE 34. GULL SELECTED FOR TEST. WINTER PHOTOGRAPH SHOWING LIGHT HEAD COLOR OF GULL

FIGURE 35. INSTALLING ECG TRANSMITTER IN HARNESS ON FERAL PIGEON ON THE DAY OF TEST

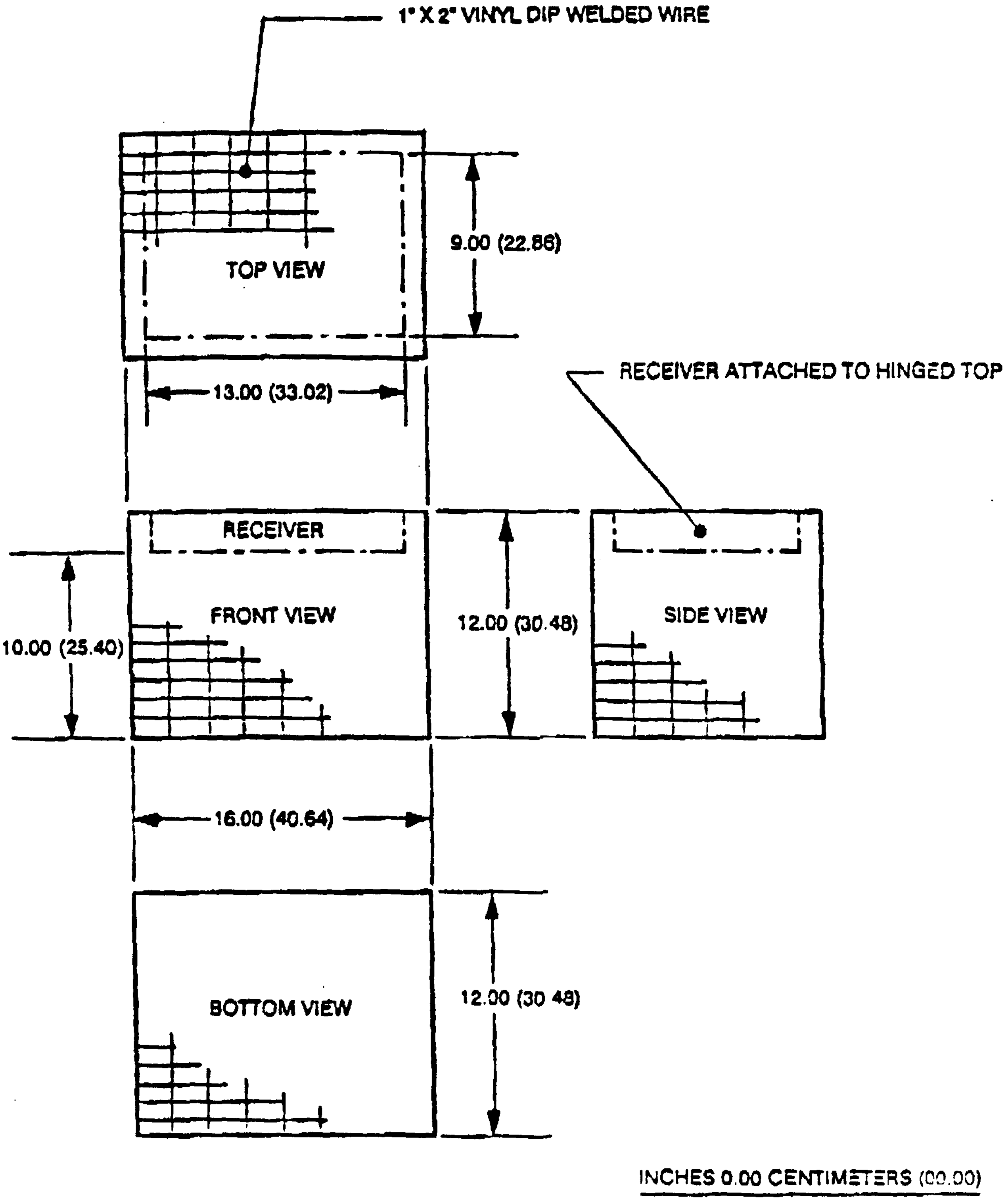


FIGURE 36. TEST CAGE FOR BIRDS WITH THE TRANSMITTER RECEIVER MOUNTED ON TOP OF CAGE

SAN ANTONIO INTERNATIONAL AIRPORT.

The San Antonio International Airport runway configuration is shown in figures 37 and 38.

The initial experimental setup was located on "Alpha" taxiway at the point of crossing 12R to 30L. This was 4,150 feet from the start of the take-off roll. The rotation point was marked on the recording data when the nose wheel lifted off the runway. When runway 3 was active, the experiment was set up on taxiway "Tango."

The aircraft selected for monitoring included Delta MD80, American 767, United 737-300, Southwest 737-300, and Continental DC-9. The time period of testing was between 3:10 pm and 3:25 pm on Monday and Tuesday of each week. This time period was chosen to allow time for the experimental setup and removal during off-peak times of the day and week.

San Antonio International Airport operations personnel assisted with vehicle escort and radio contact with FAA tower personnel for the SwRI mobile laboratory movement to and from the test site. The SwRI mobile laboratory was stored at the airport between test days.

SwRI personnel with test birds met the operations personnel at the airport center security gate and were escorted to the mobile laboratory storage site. The mobile laboratory was transported with escort to the test site according to the active runway in use at the time of the test. Control testing of birds and equipment was conducted on inactive runway sites using the same safety procedures as used on active runway tests.

Test day procedures to gain access to the test location were:

1. A telephone call was made to the airport operations officer by the SwRI project manager. Test day plans for active or inactive runways and time the SwRI personnel would arrive at the center security gate located between Terminal 1 and Terminal 2 were discussed.

2. SwRI personnel arrived at the airport center gate and signed in at the security gate with name and vehicle license number. An identification number was placed on the top of the SwRI vehicle (figure 39). SwRI personnel met with the airport operations escort for the test day.

3. The SwRI vehicle was escorted by operations personnel to the mobile laboratory storage site with operations personnel in radio contact with FAA tower personnel (figures 40 and 41).

4. The SwRI vehicle, with mobile laboratory in tow, followed the operations personnel vehicle escort (operations vehicle had a light flashing on top of the vehicle). Radio contact with the tower was used for permission to travel across taxiways and runways.

5. Airport operations personnel requested permission to close taxiway used on the test day during the experiment.

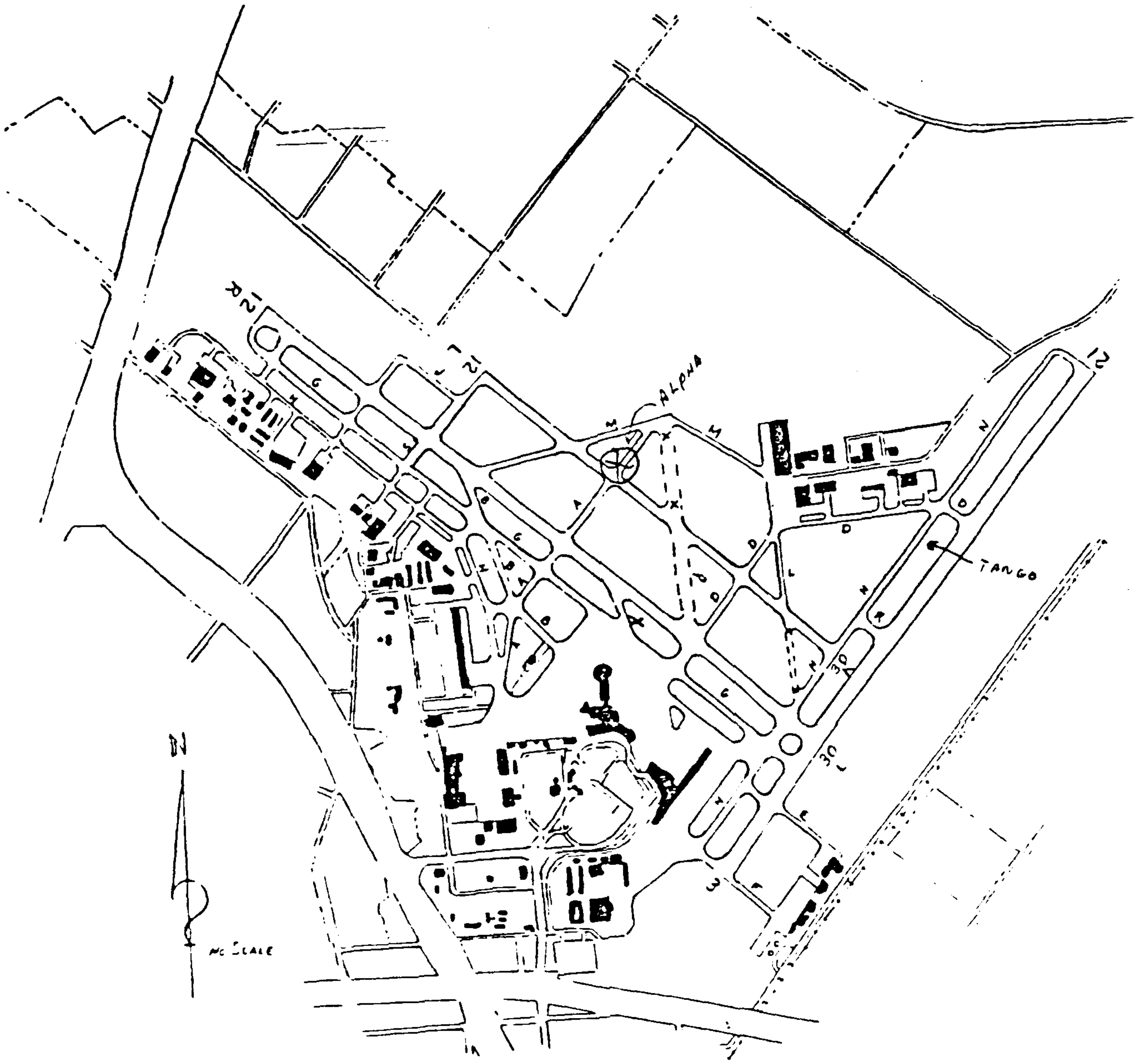


FIGURE 37. SAN ANTONIO INTERNATIONAL AIRPORT RUNWAY LAYOUT WITH TAXIWAY "ALPHA" AND "TANGO" MARKED AS LOCATION OF TEST SETUP

SAN ANTONIO INTERNATIONAL AIRPORT

Elevation - 809 feet

Ft. Remaining for Takeoffs

Taxiway	Runway 3	Runway 21
Foxtrot	7452.5	47.5
Echo	6470	1030
Golf	5930	1570
Romeo	4090	3410 (Tango)
Delta	2350	5150
November	47.5	7452.5

Ft. Remaining for Takeoffs

Taxiway	Runway 12L	Runway 30R
Juliet	5430	0
Mike	3980	1450
Alpha	3390	2040
Papa	2570	2860
Delta	1480	3950
Lima	910	4520
November	0	5430

Ft. Remaining for Takeoffs

Taxiway	Runway 12R	Runway 30L
Kilo	8090	410
Juliet	6800	1700
Sierra	6000	2500
Mike/Bravo	5110	3390
Alpha	3940	4560
Xray	2900	5600
Delta/Papa	2030	6570
November	560	7940

FIGURE 38. SAN ANTONIO INTERNATIONAL AIRPORT RUNWAY NAMES AND DISTANCES AT TAXIWAY MARKERS

FIGURE 39. SWRI PERSONNEL CHECKING IN AT SECURITY GATE AT SAN ANTONIO INTERNATIONAL AIRPORT AND RECEIVING CAR TOP IDENTIFICATION NUMBER

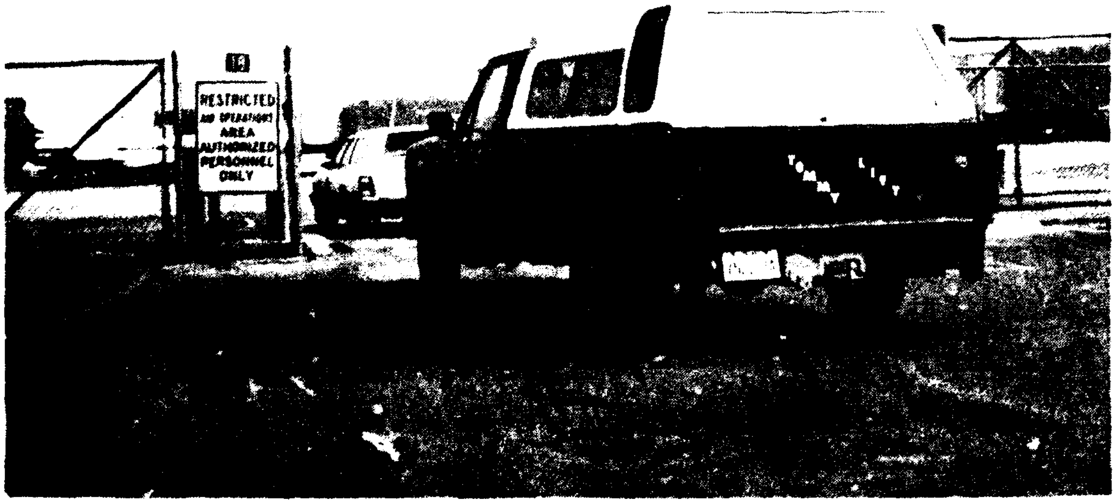


FIGURE 40. SWRI VEHICLE BEING ESCORTED INTO SECURE AREA BY AIRPORT OPERATION PERSONNEL

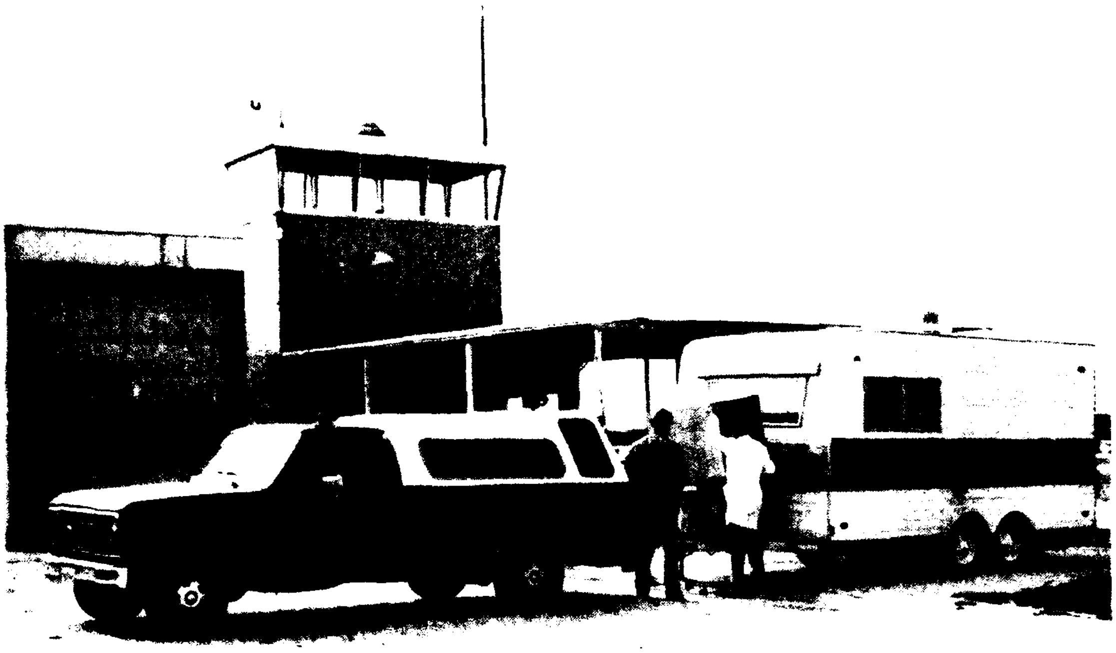


FIGURE 41. THE MOBILE LABORATORY AT THE AIRPORT STORAGE SITE IN PREPARATION FOR TOWING TO TAXIWAY TEST SITE

6. The mobile laboratory was parked outside 175-foot safety marks on the taxiway adjacent to the closest rotation point of the selected aircraft in the test (figure 42).

7. The airport operations personnel remained with the SwRI personnel. They maintained radio contact with the tower personnel with a portable radio and requested permission for personnel to walk onto the safety zone adjacent to an active runway. Personnel carried the equipment (birdcages) back and forth between mobile laboratory and test site (figures 43 and 44).

8. The first birdcage setup started in line with the runway ground lights and subsequent cages were placed 2 feet apart in a line toward the mobile laboratory. The accelerometer and sound level meter were set up beside the bird cages, and all electronic equipment was cable-connected to the mobile laboratory. A safety chain was connected to join all exposed equipment and cages at the test site (figure 26). Sandbags were also used to keep cages and boxes from moving when the aircraft passed the bird's location.

9. The bird heart rate, sound level, and ground vibration signals were recorded during the test period (figures 31 and 32).

10. The same safety procedures were followed to remove the test equipment and birds from the test site. The total time for setup and removal of equipment varied with active runway traffic; 10 to 15 minutes was required for minimum air traffic.

11. The airport operation vehicle escorted the SwRI mobile laboratory back to the storage site and escorted SwRI personnel to the center gate exit.

12. SwRI personnel checked out with the security gate personnel and returned to SwRI with the test birds.

AIRCRAFT CLOSURE RATE.

A model K-55 moving traffic radar (Doppler frequency) with graph printout of velocity was furnished by the FAA Technical Center. It was used to monitor closure rate of selected aircraft.

Accuracy of the radar was evaluated in field studies at SwRI prior to use on an active runway. Use of the Doppler radar unit on an active runway was coordinated by SwRI, airport operations personnel, and FAA tower personnel.

CONCLUSION.

Methods for collection of heart rate data from gulls and pigeons placed adjacent to runways and exposed to commercial jet aircraft during take-off were developed in Phase II, Task 1. Methods developed and applied included physiologic monitoring methods and safety procedures necessary for conducting a field study in an active metropolitan airport.

The initial plans to conduct field experiments during October, November, and December 1989 were delayed due to FAA contract modifications for equipment changes to measure aircraft closure rates. A model K-55 moving traffic radar Doppler frequency) with graph printout of velocity was furnished by the FAA

Technical Center and was used to monitor closure rate of selected aircraft during the take-off roll. Phase II, Task 2 experiments were conducted from January through May 1990.

FIGURE 42. AIRPORT OPERATIONS VEHICLE AND SWRI MOBILE LABORATORY PARKED ON TAXIWAY "ALPHA" INSIDE SAFETY MARK ACROSS TAXIWAY. THE TAXIWAY IS CLOSED TO AIRCRAFT DURING TEST PERIOD

FIGURE 43. EXPERIMENTAL EQUIPMENT SETUP BESIDE ACTIVE RUNWAY WHILE AIRPORT OPERATIONS PERSONNEL MAINTAINS RADIO CONTACT WITH FAA TOWER PERSONNEL

FIGURE 44. EXPERIMENTAL EQUIPMENT IS MOVED BACK AND FORTH BETWEEN MOBILE LABORATORY AND TEST SITE. PERSONNEL MOVE BETWEEN SAFETY AREA AND TEST SITE DURING LAG TIME BETWEEN AIRCRAFT TAKE-OFF AND LANDING

PHASE II--TASK 2--FIELD STUDY
STATISTICAL ANALYSIS OF HEART RATE RESPONSE OF BIRDS TO APPROACHING AIRCRAFT

EXPERIMENTAL FACTORS AND TEST DESIGN.

Aircraft tested were Boeing 727 (100 and 200 Series), 737 (200 and 300 Series), 767-100; and McDonnell Douglas DC-9 and McDonnell Douglas 80 Series. Air carriers were American, Continental, Delta, Southwest, and United. The experimental data were collected on all commercial carriers that departed during the test time. Several aircraft to be tested were changed in the final plans due to airline schedule and aircraft model changes. The initial plan to test the wide-body DC-10 was changed to wide-body 767 due to airline carrier model and schedule changes. Statistical analysis was conducted on the data obtained on the standard-body aircraft and wide-body aircraft.

Methods for conducting the final Task 2 field study were based on materials and methods developed during Phase I and Phase II--Task 1. The experimental design used in the field study consisted of testing 12 gulls and 12 (wild) pigeons acclimated to the sight and sound of aircraft in a realistic, environmental setting at an operating airport.

Each bird's heart rate response to the take-off sequence was measured for five different categories of standard-body and wide-body aircraft. These categories by plane type are described as follows:

1. 727-100 and 727-200 Standard-body aircraft.
   Lighting configuration consists of four lights, one on each wing next to the body and one on each wing halfway between the body and the wing tip. Engine configuration consists of three engines, one on each side at the rear portion of the aircraft body and one in the base of the tail.

2. 737-200 Standard-body aircraft.
   Lighting configuration consists of four lights, one on each wing next to the body and one on each wing halfway between the body and the wing tip. Engine configuration consists of two engines, one on each wing.

3. 737-300 Standard-body, high-bypass-ratio engine aircraft.
   Lighting configuration consists of two lights, one on each wing next to the body. Engine configuration consists of two engines, one on each wing.

4. 767-100 Wide-body, high-bypass-ratio engine aircraft.
   Lighting configuration consists of two lights, one on each wing next to the body. Engine configuration consists of two engines, one on each wing.

5. DC-9 and MD-80 Standard-body aircraft.
Lighting configuration consists of four lights, one on each wing next to the body and one on each wing tip. Engine configuration consists of two engines, one on each side at the rear portion of the aircraft body.

Each test involved placing the bird in a wire cage which was located next to the airport runway. Heart rate response measurements were assessed for every bird throughout the duration of each plane take-off sequence. Appropriate time intervals within each data collection sequence were defined so that any effect of the bird's reaction to earlier plane take-offs was minimized.

In order to investigate the bird's response to different stimuli, i.e., sight and/or sound of approaching aircraft, each bird was exposed to two experimental conditions; (1) birds placed along the runway with full view and sound of the approaching aircraft, and (2) birds placed along the runway with a blocked view and full sound of the approaching aircraft. All birds were also exposed to "control" conditions, e.g., full sight-and-sound of the environment with no planes either taking off or landing on the runway. These control measurements were taken in order to investigate the appropriate "normalization" of the heart rate data collected for each bird.

Tables 11 and 12 summarize the number of tests gathered for each individual bird, plane type, and stimulus combination.

TABLE 11. NUMBER OF SIGHT-AND-SOUND STIMULUL TESTS OBSERVED FOR EACH BIRD BY PLANE TYPE

Bird[1] No.	767-100	737-300	727-100 727-200	DC-9 MD-80	737-200	Control
G152	2	3	3	3	6	10
G156	2	3	6	3	2	26
G161	3	2	5	1	1	23
G165	2	5	4	2	3	21
G169	1	3	2	0	1	8
G170	3	2	5	1	1	27
G172	2	3	3	3	6	10
G178	2	5	6	6	2	24
G182	2	3	3	3	6	12
G185	1	3	3	2	1	25
G192	3	2	4	1	1	27
G199	1	5	4	2	3	21
P107	1	5	7	6	2	25
P111	1	1	1	0	1	20
P114	3	1	3	1	1	22
P120	1	5	3	5	1	24
P122	2	2	4	1	1	25
P123	2	5	4	2	3	21
P126	2	4	4	2	3	18
P127	2	3	3	3	6	15
P128	1	3	3	2	6	15
P132	2	1	4	1	1	28
P133	2	5	4	2	3	21
P145	1	3	1	2	5	11

[1]Designates bird type and subject number; G = gull, P = pigeon

TABLE 12. NUMBER OF SOUND-ONLY STIMULUS TESTS OBSERVED FOR EACH BIRD BY PLANE TYPE

Bird[1] No.	767-100	737-300	727-100 727-200	DC-9 MD-80	737-200
G152	2	7	5	3	2
G156	2	6	5	2	2
G161	2	4	4	4	1
G165	2	4	4	1	2
G169	0	2	2	0	2
G1700	2	4	4	4	1
G172	2	7	5	3	2
G178	2	6	5	2	2
G182	2	7	5	3	2
G185	2	6	5	2	2
G192	2	4	4	4	1
G199	2	4	4	1	2
P107	2	6	4	2	2
P111	2	6	5	3	2
P114	2	3	2	3	1
P120	2	6	5	2	2
P122	2	4	4	4	1
P123	2	4	4	1	2
P126	2	3	4	1	2
P127	1	4	4	2	1
P128	1	7	4	3	2
P132	1	3	4	2	1
P133	1	4	3	1	1
P145	1	4	3	3	1

[1]Designates bird type and subject number; G = gull, P = pigeon

RESPONSE VARIABLES.

Two response variables measured from the array of tests conducted on the gulls and pigeons employed in this study were identified for statistical analysis. These response variables are maximum heart rate, which refers to the actual maximum heart rate measured for each individual bird during the test, and average heart rate, which is computed from the actual heart rate during a selected time interval during the test. Both of these response variables were investigated under the following four scenarios:

1. Response interval about the rotation point.
2. Response interval about the maximum sound value.
3. Response interval about the maximum sound value and response variable; normalized by individual test data.
4. Response interval about the maximum sound value and response variable; normalized by "control" data.

The eight different analyses were conducted in order to evaluate the physiological heart rate response of the gulls and pigeons and are described in detail.

A. MAXIMUM HEART RATE DURING ROTATION POINT RESPONSE INTERVAL. The heart rate response interval of each bird at every test was defined to be from 10 seconds before rotation to 10 seconds after rotation. The rotation point is synonymous with the take-off point of the aircraft. The maximum heart rate during each of these 20-second response intervals was identified.

B. MAXIMUM HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL. This response interval is centered on the maximum sound as measured with the sound meter at each test. The interval was defined to include the period from 10 seconds before maximum sound to 10 seconds after maximum sound. The maximum heart rate during each of these 20-second response intervals was identified.

C. NORMALIZED MAXIMUM HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY INDIVIDUAL TEST. The data identified in this response interval are the same as that defined above, except it has been normalized to each individual test. This normalization measures the maximum heart rate percent change from the baseline, where baseline, B, is defined as the average heart rate from 15 to 10 seconds before maximum sound value.

$$\text{Normalized Maximum Heart Rate} = \frac{(A - B)}{B} * 100$$

where A = average heart rate in interval defined as 10 seconds before maximum sound to 10 seconds after maximum sound

and B = average heart rate in interval defined as 15 seconds to 10 seconds before maximum sound.

Normalization is a method by which one can compute the change in the heart rate by comparing it to the baseline; in this case, the average heart rate in the 5-second interval before the true response interval for each individual test. Figures 45 and 46 illustrate the average percent change from the baseline (e.g., normalized) of the maximum heart rates measured on the gulls and pigeons, respectively, in this study. The average percent change is plotted for each plane type along with lines which extend to two standard deviations from the average value.

D. MAXIMUM HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY CONTROL TESTS. This response variable is similar to that outlined previously except the normalization method uses the average of all the control tests run on each individual bird as the baseline value, B.

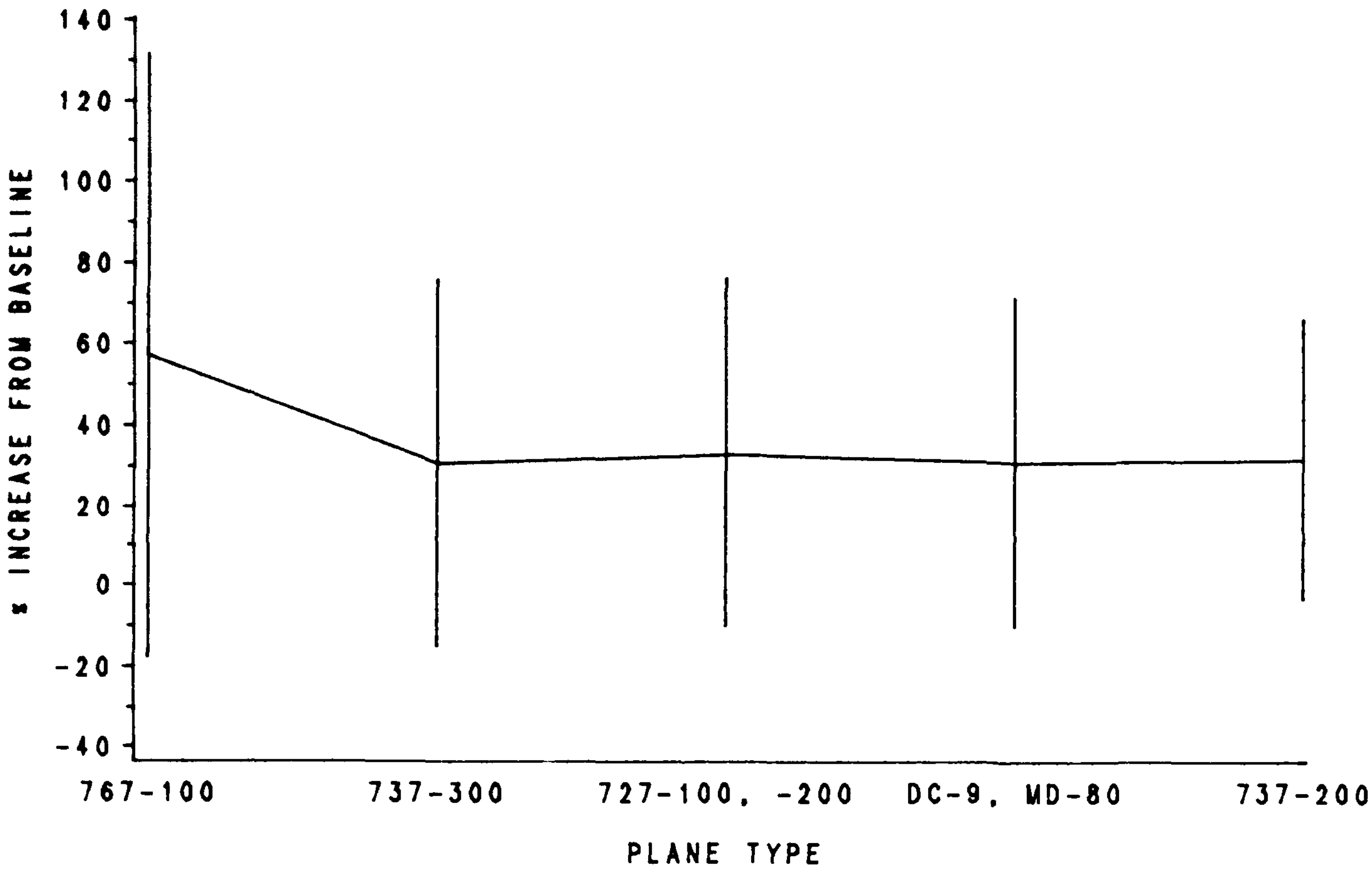


FIGURE 45. MEAN NORMALIZED MAXIMUM HEART RATE OF GULLS BY PLANE TYPE

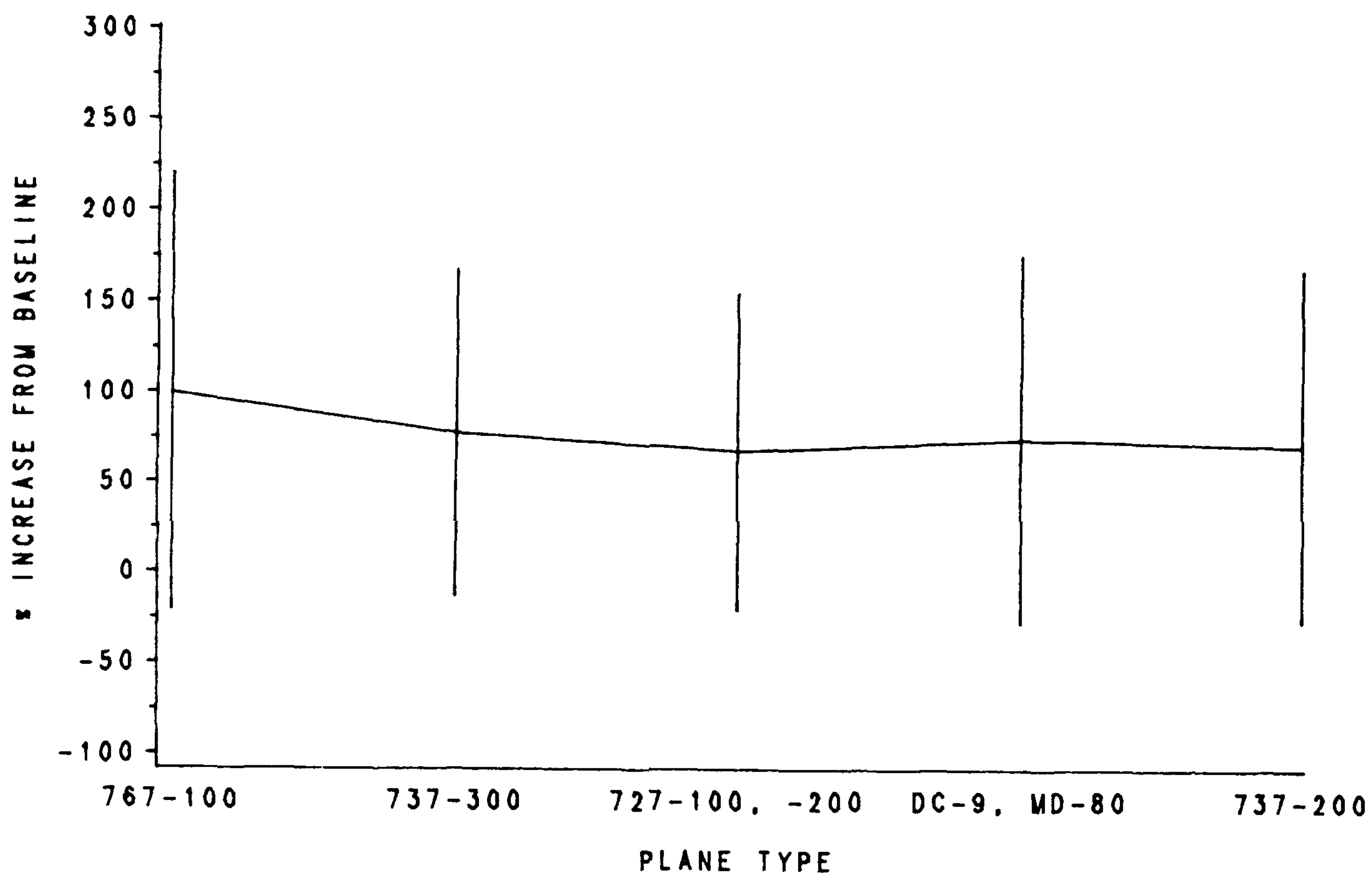


FIGURE 46. MEAN NORMALIZED MAXIMUM HEART RATE OF PIGEONS BY PLANE TYPE

$$\text{Normalized Maximum Heart Rate} = \frac{(A - B)}{B} * 100$$

where A = maximum heart rate in interval defined as 10 seconds before maximum sound to 10 seconds after maximum sound

and B = average heart rate for all the control runs for an individual bird.

The assumption in this normalization equation is that each bird has a baseline, or resting, heart rate which could be measured by recording each bird's heart rate after they were placed alongside the runway, but were not exposed to any aircraft taking off. Each bird was subjected to this "control" situation a number of different times and on different days. A composite average (variable B above) over all test durations and test days was computed for each bird.

Figures 47 and 48 illustrate typical frequency distributions of all the heart rate measurements taken on two different gulls. Gull No. 165 portrays an "expected" distribution of heart rate data with an average resting heart rate near 275 in figure 47, while figure 48 depicts a bimodal-type distribution of resting heart rate for gull No. 169. Close scrutiny of the data for gull No. 169 reveals that the data centered around 200 were taken on January 9, 1990, while the data centered around 360 were taken on May 24, 1990. Therefore, it would be inappropriate to normalize each bird's heart rate by the control data since the control data do not represent an accurate estimate of the resting heart rate. However, analyses were conducted using this criteria and are included in this report for completeness.

E. AVERAGE HEART RATE DURING ROTATION POINT RESPONSE INTERVAL. This interval is like A but uses the mean heart rate instead of the maximum heart rate. Similarly, the response interval was defined to be from 10 seconds before rotation to 10 seconds after rotation. The rotation point is synonymous with the take-off point. The average heart rate during each of these 20-second response intervals was calculated.

F. AVERAGE HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL. This response interval is centered around the maximum sound as measured with the sound meter. The interval was defined to be from 10 seconds before maximum sound to 10 seconds after maximum sound. The average heart rate during each of these 20-second response intervals was computed.

G. AVERAGE HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY INDIVIDUAL TEST. The data identified in this response interval are the same as that defined in F, except it has been normalized to each individual test. This normalization will measure the average heart rate percent change from the baseline, where baseline, B, is defined as the average heart rate from 15 to 10 seconds before maximum sound value.

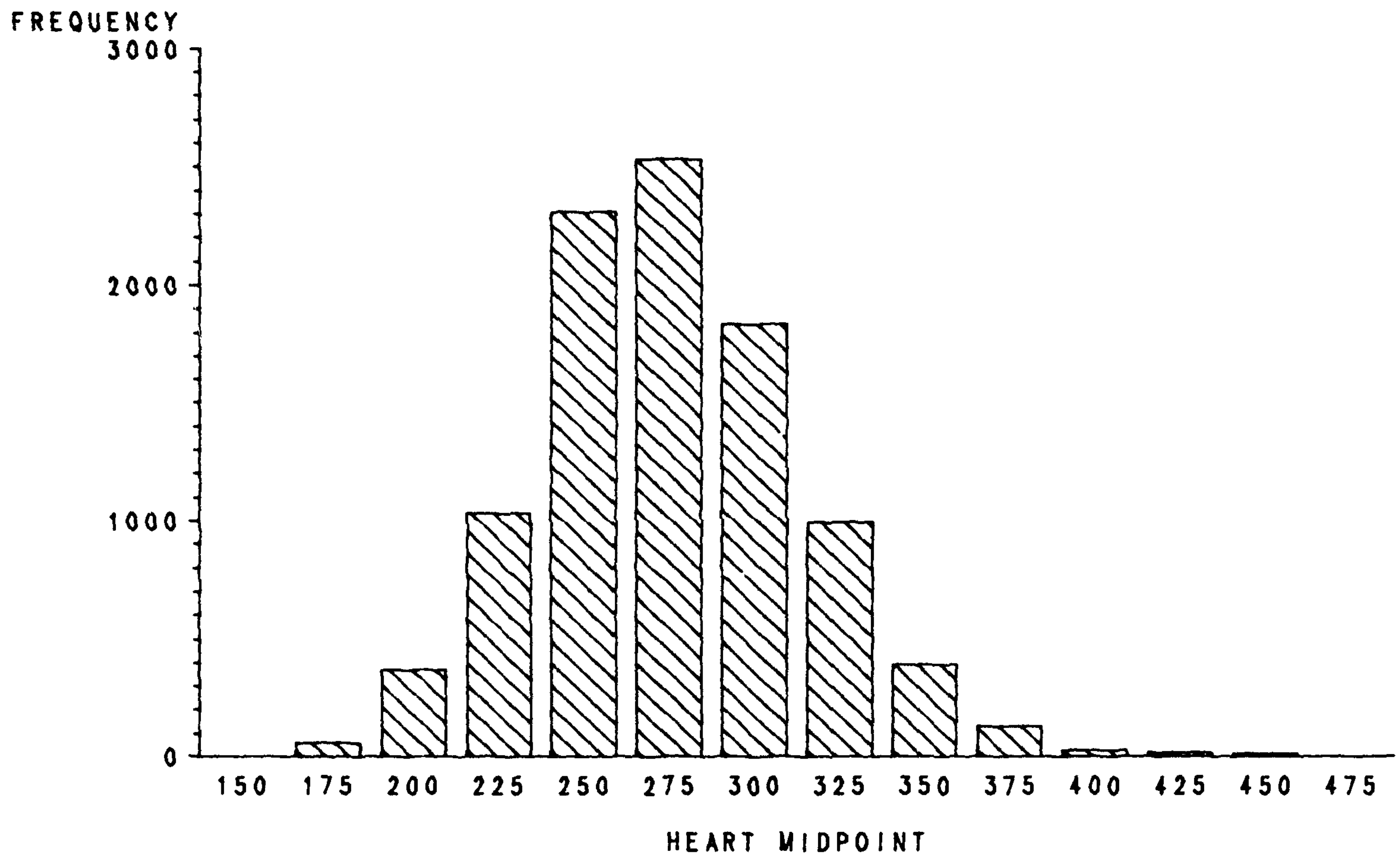


FIGURE 47. CONTROL DATA HEART RATE DISTRIBUTION OF GULL NO. 165

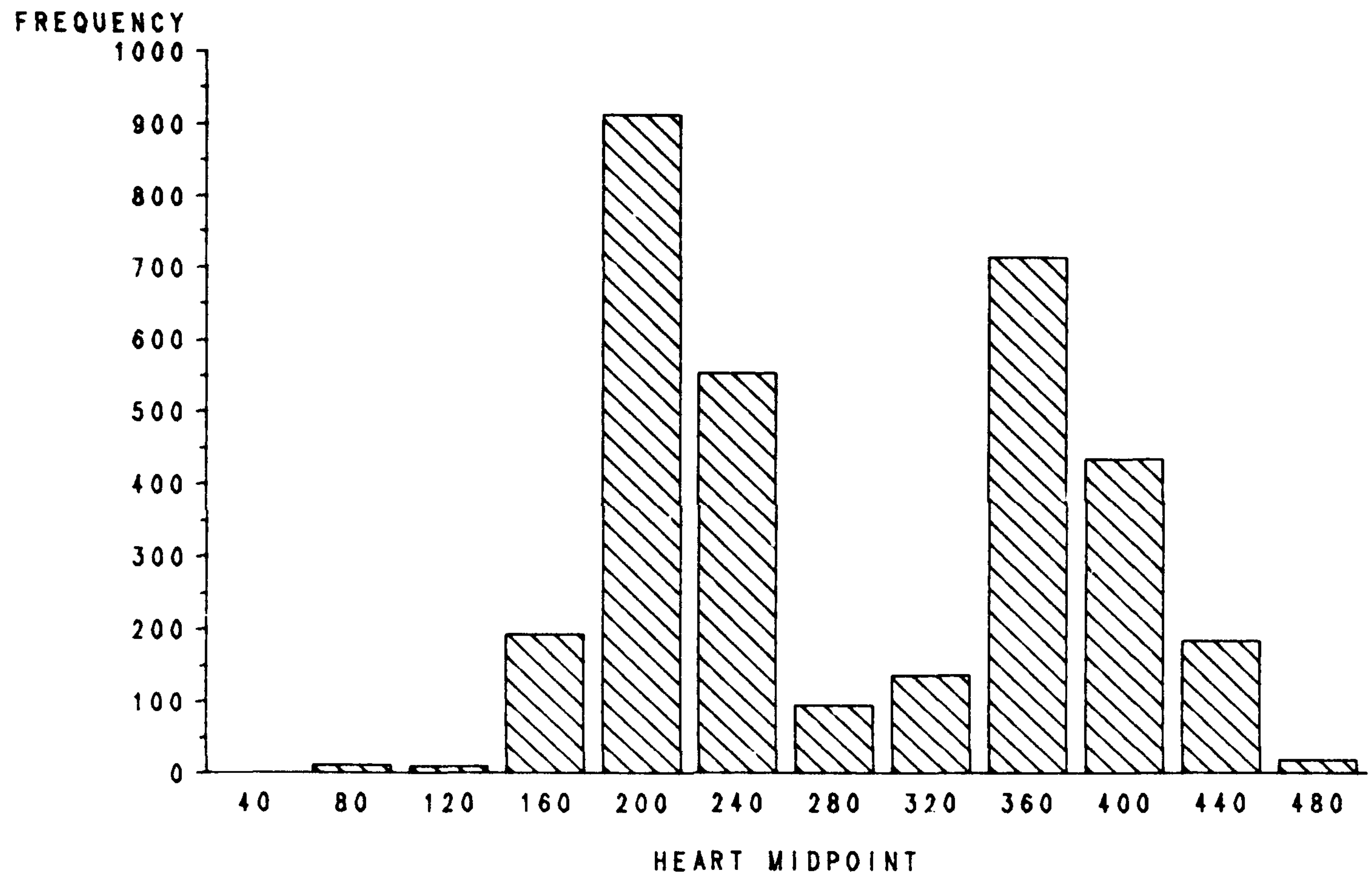


FIGURE 48. CONTROL DATA HEART RATE DISTRIBUTION OF GULL NO. 169

$$\text{Normalized Maximum Heart Rate} = \frac{(A - B)}{B} * 100$$

where A = maximum heart rate in interval defined as 10 seconds before maximum sound to 10 seconds after maximum sound

and B = average heart rate in interval defined as 15 seconds to 10 seconds before maximum sound.

Figures 49 and 50 illustrate the average percent change from the baseline (e.g., normalized) of the average heart rates measured on the gulls and pigeons, respectively, in this study. The average percent change is plotted for each plane type along with lines which extend to two standard deviations from the average value.

<u>H. AVERAGE HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY CONTROL TESTS</u>. This response variable is similar to that outlined above, except the normalization method uses the average of all the control tests run on each individual bird as the baseline value, B.

$$\text{Normalized Maximum Heart Rate} = \frac{(A - B)}{B} * 100$$

where A = average heart rate in interval defined as 10 seconds before maximum sound to 10 seconds after maximum sound

and B = average heart rate for all the control runs for an individual bird.

The assumption in this normalization equation is that each bird has a baseline, or resting, heart rate which could be measured by recording each bird's heart rate after they were placed alongside the runway, but were not exposed to any aircraft taking off. Each bird was subjected to this "control" situation a number of different times and on different days. A composite average (variable B above) over all test durations and test days was computed for each bird.

<u>STATISTICAL METHODOLOGY</u>.

The statistical technique, ANOVA, (references 2,3,4) was used to determine whether or not significant differences exist among the means of groups of observations. This type of analysis was pertinent to this study in that it consisted of an examination and identification of the sources of variation present in the eight response variables. The experimental design enabled the primary sources of variability to be defined and the amount of variability due to each of the represented sources to be separated out of the total variability in the response data. Further, two-way interactions involving bird type were also tested for statistical significance. The results from the appropriate ANOVA for each of the eight response variables are given in the following section.

Several independent variables (main effects or factors) were chosen in this study to investigate the effects, if any, they have on each of the eight

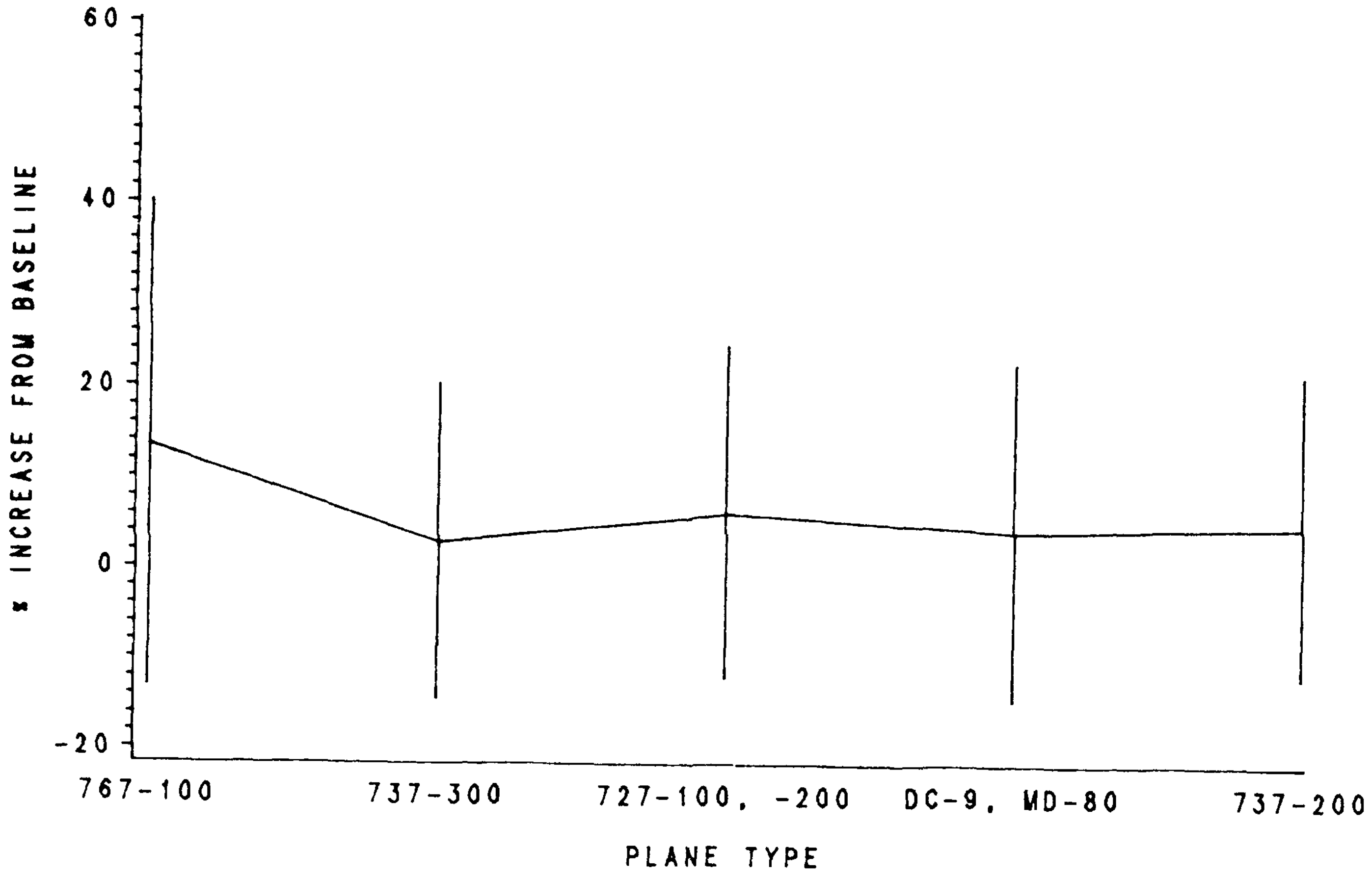


FIGURE 49. MEAN NORMALIZED AVERAGE HEART RATE OF GULLS BY PLANE TYPE

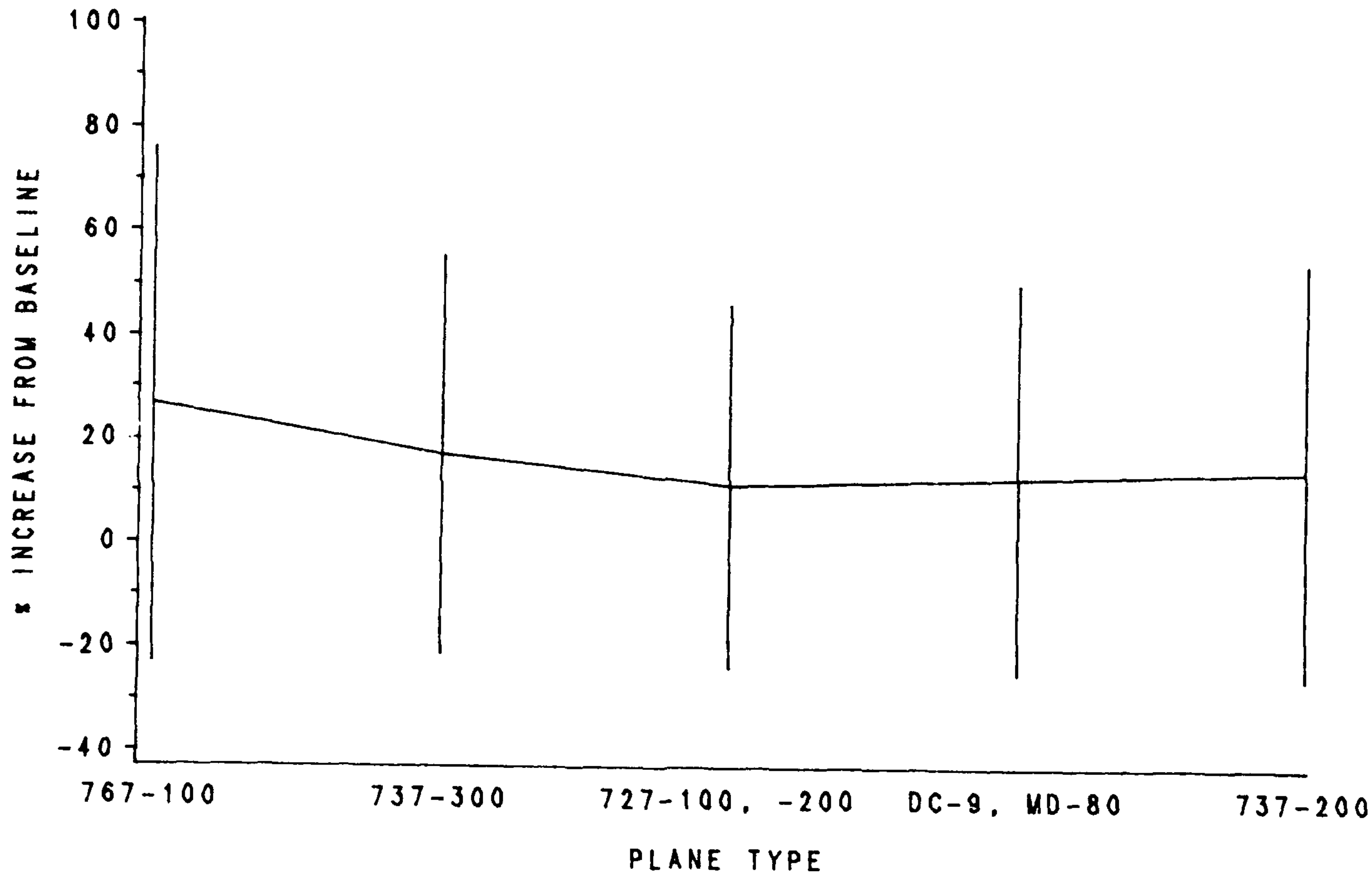


FIGURE 50. MEAN NORMALIZED AVERAGE HEART RATE OF PIGEONS BY PLANE TYPE

dependent (response) variables identified previously. Basically, all eight response variables reflect variety among only two response: maximum heart rate and average heart rate. The main effects under scrutiny are Bird (gull and pigeon), Plane (767-100, 737-300, 727-100 and 727-200, DC-9 and MD-80, and 737-200) and Stimuli (sight-and-sound and sound-only).

The analyses involving the maximum heart rate had an additional independent variable, Take-off, which was set to -1 if the maximum heart rate occurred before the rotation point and +1 if the maximum occurred after the rotation point. This factor was included in the model to test whether the average maximum heart rate was different depending on whether it occurred before or after plane take-off.

Two-way interactions involving the bird and other main effects were also included in the ANOVA model. Lastly, because all the birds were not exposed to both the sight-and-sound and sound-only stimulus on the same day, a Date factor was included in the model as a nested effect within Stimulus. Thus, the resulting ANOVA model used is as follows:

Source

Main Effects:

Plane
Bird
Stimulus
Take-off

Two-way Interactions:

Bird*Stimulus
Bird*Plane
Bird*Take-off

Nested Effects:

Date(Stimulus)
Bird*Date(Stimulus)

None of the analyses with the average heart rate response variables included the Take-off main effect or the Bird*Take-off interaction in the ANOVA model.

The results from the ANOVAs were tested at the 5 percent level of significance. The assumptions of constant variance of the residuals, normality, and randomness needed in order to use the ANOVA techniques were met in all cases. If any main effects were found to be significant, additional tests were computed to determine which levels of the main effects produced average response values that were different from each other. These techniques are known as multiple comparison tests on means (references 5,6). The specific test used in this investigation was the Tukey-Kramer method which is useful when you have an unequal number of observations in the levels of the main effects.

STATISTICAL RESULTS.

Each of the eight scenarios identified were analyzed using ANOVA techniques. The analysis which best describes the variation present in the response data, e.g., statistically significant differences in the average response for different factor levels, is given below.

A. MAXIMUM HEART RATE DURING ROTATION POINT RESPONSE INTERVAL. An investigation of the maximum heart rate response of the birds during an interval around the rotation point was performed using statistical analysis of variance techniques. Two significant main effects were identified: Bird and Plane. The calculated p-values for Bird and Plane are $p < 0.0001$ and $p < 0.0001$. Thus, the average of all the maximum heart rates measured during the rotation point interval was statistically different between the two types of birds and among the five different plane types.

Table 13 lists the average of the maximum heart rates by significant main effects. Gulls had a significantly higher average maximum heart rate than pigeons. A multiple comparison test was used to distinguish which plane types generated maximum heart rates that were significantly different on the average than the others. Birds exposed to the 767 wide-body planes experienced statistically higher ($p < 0.0001$) maximum heart rates on the average than the other four plane types. The data reveal that there were no significant differences in the average maximum heart rate among the remaining four standard-body plane types. The nested effects of Date(Stimulus) and Bird*Date(Stimulus) were statistically significant in all the eight analyses presented in this study. This is not unusual because different birds were exposed to different planes on different days. Since the day effect was significant, all variation attributed to it was partitioned appropriately so that the remaining effects could be tested correctly.

TABLE 13. AVERAGE OF MAXIMUM HEART RATE IN ROTATION POINT INVERVAL

Bird	Sample Size	Average
Gull	357	400.40
Pigeon	321	251.32

Plane	Sample Size	Average
767-100	85	381.75
737-300	192	328.44
727-100,727-200	186	327.98
DC-9, MD-80	110	324.66
737-200	105	300.77

B. MAXIMUM HEART RATE DURING MAXIMUM SOUND INTERVAL. The maximum heart rate response of the birds during the interval around the maximum sound was examined next. The maximum sound level is a more realistic defining point in determining when the plane actually passes the bird. Lighter planes generally take-off sooner than heavier planes, and therefore, the rotation point is often before the plane actually passes the bird. Using the maximum sound response interval, two significant main effects were identified: Bird and Plane. The calculated p-values for Bird and Plane are $p < 0.0001$. Thus, the

average of all the maximum heart rates measured during the bird's response interval about the maximum sound point was statistically different between the two types of birds and among the five different plane types.

Table 14 lists the average of the maximum heart rates by significant main effects. As seen in the first analysis, gulls had a significantly higher average maximum heart rate. Similar results were also noted in the plane type. Birds exposed to wide-body 767 planes had significantly higher average maximum heart rates than the other four planes.

TABLE 14. AVERAGE OF MAXIMUM HEART RATE IN MAXIMUM SOUND INTERVAL

Bird	Sample Size	Average
Gull	357	404.27
Pigeon	321	254.23
Plane	**Sample Size**	**Average**
767-100	85	395.18
737-300	192	330.82
727-100,727-200	186	328.96
DC-9, MD-80	110	325.27
737-200	105	303.43

C. MAXIMUM HEART RATE DURING MAXIMUM SOUND INTERVAL; NORMALIZED BY INDIVIDUAL TEST. An analysis of variance was performed which identified three significant main effects: Bird, Plane and Take-off. The calculated p-values for Bird, Plane and Take-off are $p < 0.0001$, $p < 0.0001$ and $p < 0.0044$, respectively. Thus, the mean of the normalized maximum heart rate during the response interval measured for each bird was statistically different between the two types of birds, among the five different plane types, and between the two measures of aircraft take-off. Table 15 lists the mean of the normalized maximum heart rate during the response interval by main effects.

Multiple comparison tests were again used to distinguish which levels of the effects were statistically different. Using this response variable, pigeons had a significantly higher average normalized maximum heart rate than the gulls. Also, birds subjected to the 767 wide-body planes possessed a significantly higher mean normalized maximum heart rate than the other four plane types. The final significant main effect was Take-off. Recall that the interval being analyzed is ± 10 seconds about the maximum sound value. This occurs when the plane crosses the bird sitting on the runway. If the maximum heart rate occurred before the plane crossed the bird, then take-off was set to -1. Not surprisingly, the average normalized maximum heart rate was higher when the maximum occurred after the plane crossed the bird than before it crossed the bird.

TABLE 15. AVERAGE OF MAXIMUM HEART RATE IN MAXIMUM SOUND INTERVAL; NORMALIZED BY INDIVIDUAL TEST

Bird	Sample Size	Average
Pigeon	321	76.42%
Gull	357	35.11%
Plane	**Sample Size**	**Average**
767-100	85	81.04%
737-300	192	52.75%
DC-9, MD-80	110	51.61%
737-200	105	50.43%
727-100, 727-200	186	48.79%
Take-off	**Sample Size**	**Average**
After take-off	369	66.10%
Before take-off	309	41.01%

D. MAXIMUM HEART RATE DURING MAXIMUM SOUND INTERVAL; NORMALIZED BY CONTROL TESTS. ANOVA techniques were performed on the normalized maximum heart rate during the maximum sound interval. This response was achieved by normalizing by each bird's average control tests. Pigeons again demonstrated significantly higher average maximum heart rates than gulls (p-value <0.0001), as shown in table 16. Plane types also were found to be a significant factor with 767 wide-body planes generating the highest average normalized maximum response (p-value <0.0001). Also significant in this analysis was the interaction between Bird and Stimulus (p-value 0.0033). As can be seen with the data (figure 51), pigeons have a higher percent change from baseline with respect to maximum heart rate response, and that there is an increase in the mean maximum heart rate response from the sound-only stimulus to the sight-and-sound stimulus. This is not the case for the gulls.

Although the mean values of the maximum heart rate are smaller for the gulls than the pigeons, there is a decrease in the average maximum heart rate from the sound-only stimulus to the sight-and-sound stimulus.

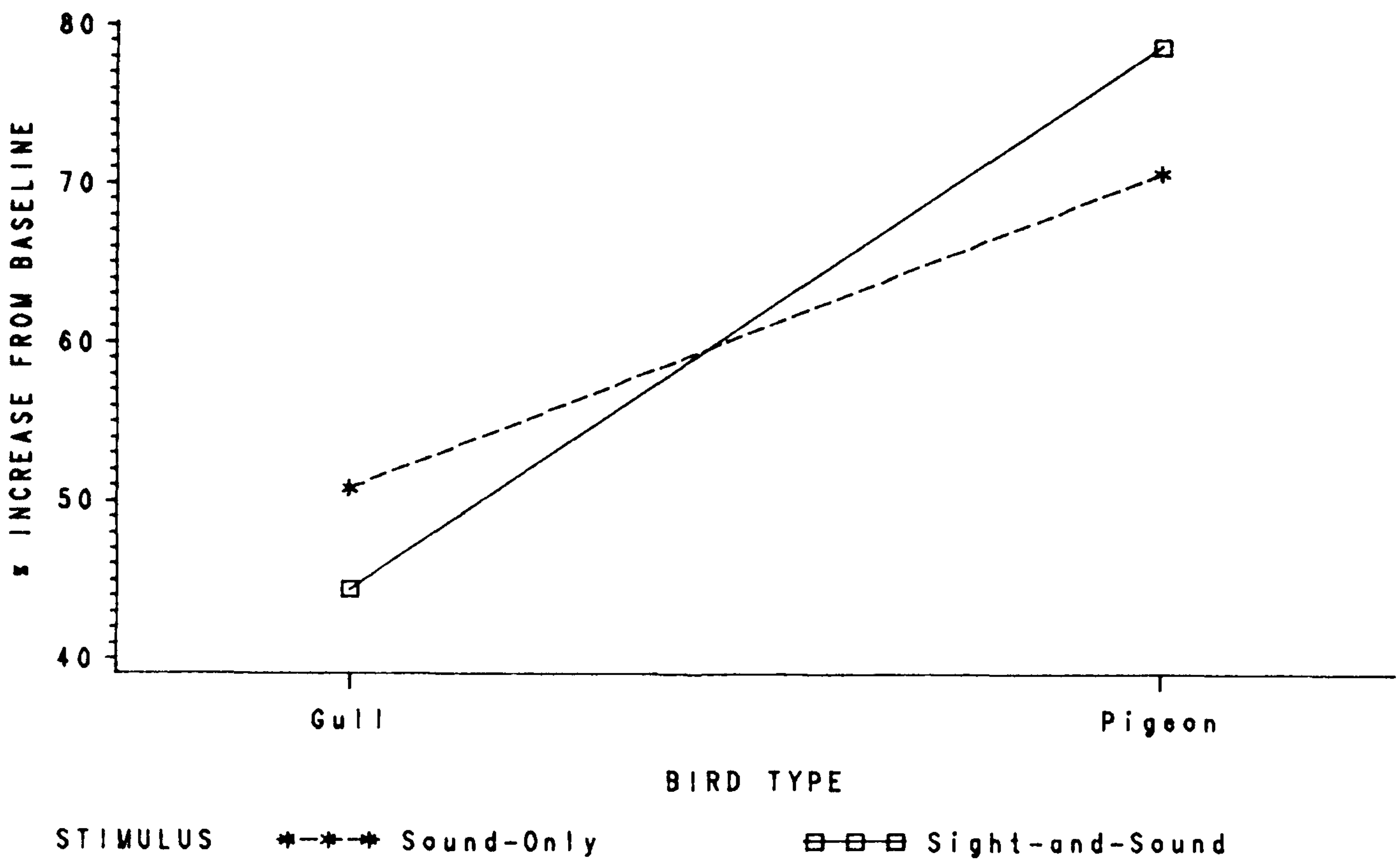


FIGURE 51. AVERAGE NORMALIZED (BY INDIVIDUAL TEST) MAXIMUM HEART RATE BY BIRD AND STIMULUS

TABLE 16. AVERAGE OF MAXIMUM HEART RATE IN MAXIMUM SOUND INTERVAL; NORMALIZED BY CONTROL TESTS

Bird	Sample Size	Average
Pigeon	321	74.68%
Gull	357	47.74%

Plane	Sample size	Average
767-100	85	89.18%
737-300	192	59.35%
727-100, 727-200	186	58.23%
DC-9, MD-80	109	58.04%
737-200	105	46.03%

Bird	Stimulus	Sample Size	Average
Pigeon	Sound Only	163	70.73%
Pigeon	Sight & Sound	158	78.75%
Gull	Sound Only	185	50.79%
Gull	Sight & Sound	171	44.43%

E. AVERAGE HEART RATE DURING ROTATION POINT INTERVAL. Only one statistically significant main effect was identified: Bird (p-value <0.0001). Thus, the mean of all the average heart rates measured during the bird's response interval about the rotation point was statistically different between the two types of birds as noted in table 17. Gulls had a significantly higher mean average heart rate (by almost 100 percent) than pigeons.

TABLE 17. MEAN OF AVERAGE HEART RATE IN ROTATION POINT INTERVAL

Bird	Sample Size	Average
Gull	357	318.42
Pigeon	321	165.37

F. AVERAGE HEART RATE DURING MAXIMUM SOUND INTERVAL. The average heart rate response of the birds during an interval around the maximum sound was examined next. Using the maximum sound response interval, only one significant main effect was identified: Bird (p-value <0.0001). Thus, the average of all the maximum heart rates measured during the bird's response interval about the maximum sound point was statistically different across the two types of birds. Table 18 enumerates the average of the maximum heart rates by bird type. As seen in the previous analysis, the gulls again possessed a significantly higher average maximum heart rate (again by almost 100 percent) than the pigeons.

TABLE 18. MEAN OF AVERAGF HEART RATE IN MAXIMUM SOUND INTERVAL

Bird	Sample Size	Average
Gull	357	321.28
Pigeon	321	170.09

G. AVERAGE HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY INDIVIDUAL TEST. An analysis of variance was performed which identified two significant main effects: Bird and Plane. The calculated p-values for Bird and Plane are $p < 0.0001$ and $p < 0.0001$. Thus, the mean of the normalized maximum heart rate during the response interval measured for each bird was statistically different between the two types of birds and among the five different plane types. Table 19 lists the mean of the normalized maximum heart rate during the response interval by main effects.

Pigeons had a significantly higher average normalized maximum heart rate than the gulls. Also, birds exposed to the 767 wide-body planes possessed a significantly higher mean normalized maximum heart rate than the other four plane types.

TABLE 19. MEAN OF AVERAGE HEART RATE IN MAXIMUM SOUND INTERVAL NORMALIZED BY INDIVIDUAL TEST

Bird	Sample Size	Average
Pigeon	321	15.62%
Gull	357	5.72%

Plane	Sample Size	Average
767-100	85	19.55%
737-300	192	9.63%
737-200	105	9.55%
727-100, 727-200	186	8.72%
DC-9, MD-80	110	8.37%

H. AVERAGE HEART RATE DURING MAXIMUM SOUND RESPONSE INTERVAL; NORMALIZED BY CONTROL TESTS. Plane type was found to be a significant factor, with 767 wide-body planes generating the highest average normalized average response (p-value = 0.0077), as exhibited in table 20. Also significant in this analysis was the interaction between Bird and Stimulus (p-value <0.0001). As can be seen with the data (figure 52), pigeons have a lower average percent change from baseline with respect to maximum heart rate response than the gulls during the sound-only stimulus. Conversely, pigeons have a higher average percent change from the baseline with respect to maximum heart rate response than the gulls.

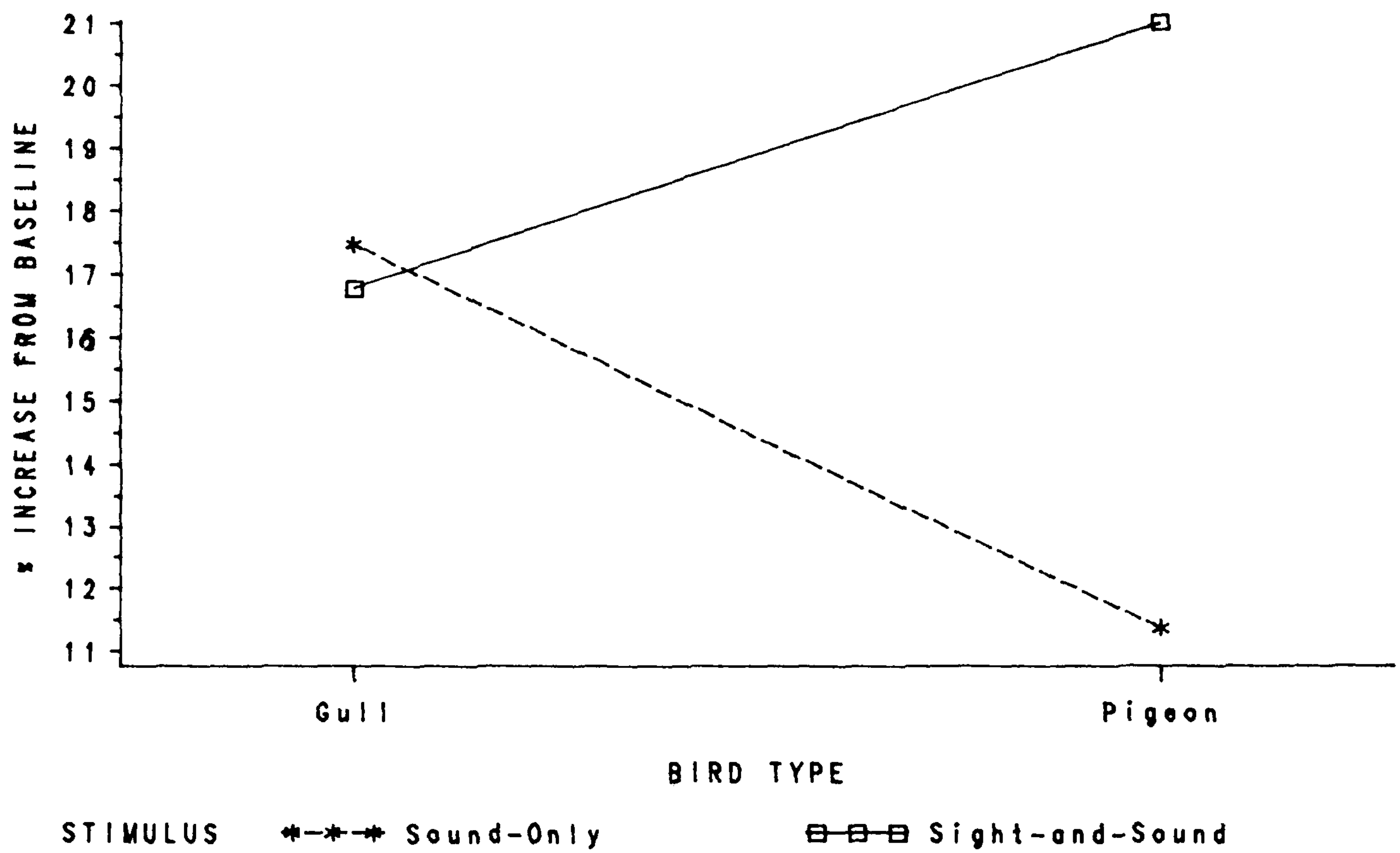


FIGURE 52. AVERAGE NORMALIZED (BY CONTROLS) MAXIMUM HEART RATE BY BIRD AND STIMULUS

TABLE 20. MEAN OF AVERAGE HEART RATE IN MAXIMUM SOUND INTERVAL; NORMALIZED BY CONTROL TESTS

Plane	Sample Size	Average
767-100	85	27.78%
727-100, 727-200	186	17.23%
737-300	192	17.14%
DC-9, MD-80	109	14.34%
737-200	105	8.12%

Bird	Stimulus	Sample Size	Average
Pigeon	Sound Only	163	11.38%
Pigeon	Sight & Sound	158	21.00%
Gull	Sound Only	185	17.46%
Gull	Sight & Sound	171	16.77%

AIRCRAFT CLOSURE RATE RESULTS.

Closure rate of each aircraft was not obtained during each test due to runway configurations. For example, when aircraft were using runway 12R on the day of the test, the line of sight for the Doppler radar was interrupted by an elevated runway area between the start of the take-off roll and the 4000-foot marker; and a clean signal was not received by the Doppler unit. During the majority of the test days, the prevailing wind had runway 12R in use. Closure rate data was obtained for 11 aircraft departures on runway 30L. The aircraft speeds were averaged by the aircraft type for the 11 aircraft departures and are presented in table 21 as a typical closure rate for the chosen aircraft in the study.

The average maximum heart rate response of each of the test birds used for the complete study was compared against the typical closure rate for each type aircraft. The maximum sound was used as the point the aircraft passed the bird location. The event was marked on the recorder when the nose of the aircraft was adjacent to the bird location, and the time was measured to the peak sound level. The time lapse averaged 3 seconds to the peak sound level after the event was marked.

The runway footage markers were used as references for distance for the event markers on the recorder: (1) at the start of the take-off roll, (2) at 2000 feet, (3) at 3000 feet, and (4) final event marked when the aircraft nose reached the bird location.

The results as presented on the closure rate on table 21 placed the bird at the "0" foot mark viewing the aircraft as it was closing on the bird location. When the aircraft reached the 2000-foot marker, the aircraft was 1800 feet from the bird; at the 3000-foot marker, the aircraft was 800 feet from the bird; and at the final mark, the aircraft was at the bird location.

This gave a bird location view of the approaching aircraft and the ability to compare average heart rate response of the birds to the aircraft closure rate at the different distances from the bird.

TABLE 21. AVERAGE HEART RATE BY CLOSURE AND DISTANCE

Bird Type	Miles per Hour Aircraft Speed Closure Rate	Plane Type	Distance[1]	Avg. Heart Rate
Pigeon	143.5	737-200	0	177.1633
Pigeon	145.0	727-100/200	0	202.6512
Pigeon	148.0	DC-9, MD-80	0	199.2830
Pigeon	152.0	737-300	0	180.3483
Pigeon	160.0	767-100	0	203.0811
Pigeon	130.0	737-200	-800	143.5490
Pigeon	140.0	DC-9, MD-80	-800	153.1923
Pigeon	141.0	727-100/200	-800	157.0698
Pigeon	150.0	737-300	-800	148.8478
Pigeon	156.0	767-100	-800	172.1026
Pigeon	104.0	737-200	-1800	145.9216
Pigeon	109.0	727-100/200	-1800	157.5233
Pigeon	112.0	DC-9, MD-80	-1800	151.8077
Pigeon	116.0	737-300	-1800	146.6222
Pigeon	128.0	767-100	-1800	158.1053
Gull	143.5	737-200	0	334.6415
Gull	145.0	727-100/200	0	359.3958
Gull	148.0	DC-9, MD-80	0	347.9298
Gull	152.0	737-300	0	360.0101
Gull	160.0	767-100	0	373.9783
Gull	130.0	737-200	-800	303.2222
Gull	140.0	DC-9, MD-80	-800	312.4561
Gull	141.0	727-100/200	-800	326.8878
Gull	150.0	737-300	-800	321.6500
Gull	156.0	767-100	-800	334.8913
Gull	104.0	737-200	-1800	286.0577
Gull	109.0	727-100/200	-1800	309.7500
Gull	112.0	DC-9, MD-80	-1800	298.2456
Gull	116.0	737-300	-1800	318.4646
Gull	128.0	767-100	-1800	300.4783

(1) Distance is measured from the plane to the bird.
Distance = 0 indicates that the plane is even with the bird.
Distance = -800 indicates that the plane is 800 feet before the bird.

Figures 53 and 54 show the average heart rate versus the distance from the pigeons and gulls. The heart rate response of the pigeons on figure 53 does not indicate recognition of the aircraft as danger until the aircraft is 800 feet from the bird, except for the heart rate increase response to the wide-body 767. The gulls on figure 54 indicate recognition of the approaching aircraft 1800 feet away and show an increased heart rate response almost linear as the aircraft closes on the bird.

Figures 55 and 56 show the average heart rate versus the closure rate (speed of the aircraft) as the aircraft approaches the bird. The average heart rate response of the birds increases dramatically as the aircraft speed increases and closes on the bird.

ACCELEROMETER RESULTS.

The accelerometer was deleted from the field test when a preliminary analysis indicated no apparent difference between ground vibrations and peak sound level as aircraft approached and passed the test bird location. No attempt was made to isolate the accelerometer readings from the peak sound level because testing was done to see if some early warning to the bird may be indicated by the tactile response of the bird's feet and the ground vibration of the approaching aircraft before the sound level increase indicated the approach of the aircraft. The tactile response did not indicate a reliable clue for an early warning to alert the bird to the approaching aircraft.

SOUND LEVEL RESULTS.

Ambient or background noise levels on and around the airport were recorded at 50 to 60 dB. The take-off engine noise was 120 to 140 dB as the aircraft passed the test bird location alongside the runway. The peak sound level occurred about 3 seconds after the front of the aircraft passed the test bird's location. If the peak sound was the only stimulus that would cause the bird to move away from the approaching aircraft, then the bird would not have time to avoid a collision with the aircraft or ingestion into the engine.

BIRD HEALTH AND CARE RESULTS.

The feral pigeons that were trapped while residing adjacent to the San Antonio International Airport were housed as a social group in the SwRI aviary. A roost platform was provided that was similar to nesting sites under concrete overpasses and airport structures.

The gulls were trapped adjacent to the Corpus Christi Airport and housed at the SwRI aviary. The birds were randomly selected, banded for identification, and placed in test group cages for normal social activity. Sand was used on the ground, as well as on the base of an elevated platform that was located in the weather protected area at one end of the open air cage. Feed pans were placed in a shallow wading tray, and a separate water bath was provided.

No medication was required to maintain the captive gulls and pigeons. Parasites were kept minimum by maintaining a strict diet and sanitary utensil control. Excess noise and personnel movement in the aviary area was kept at a minimum to reduce stress on the birds.

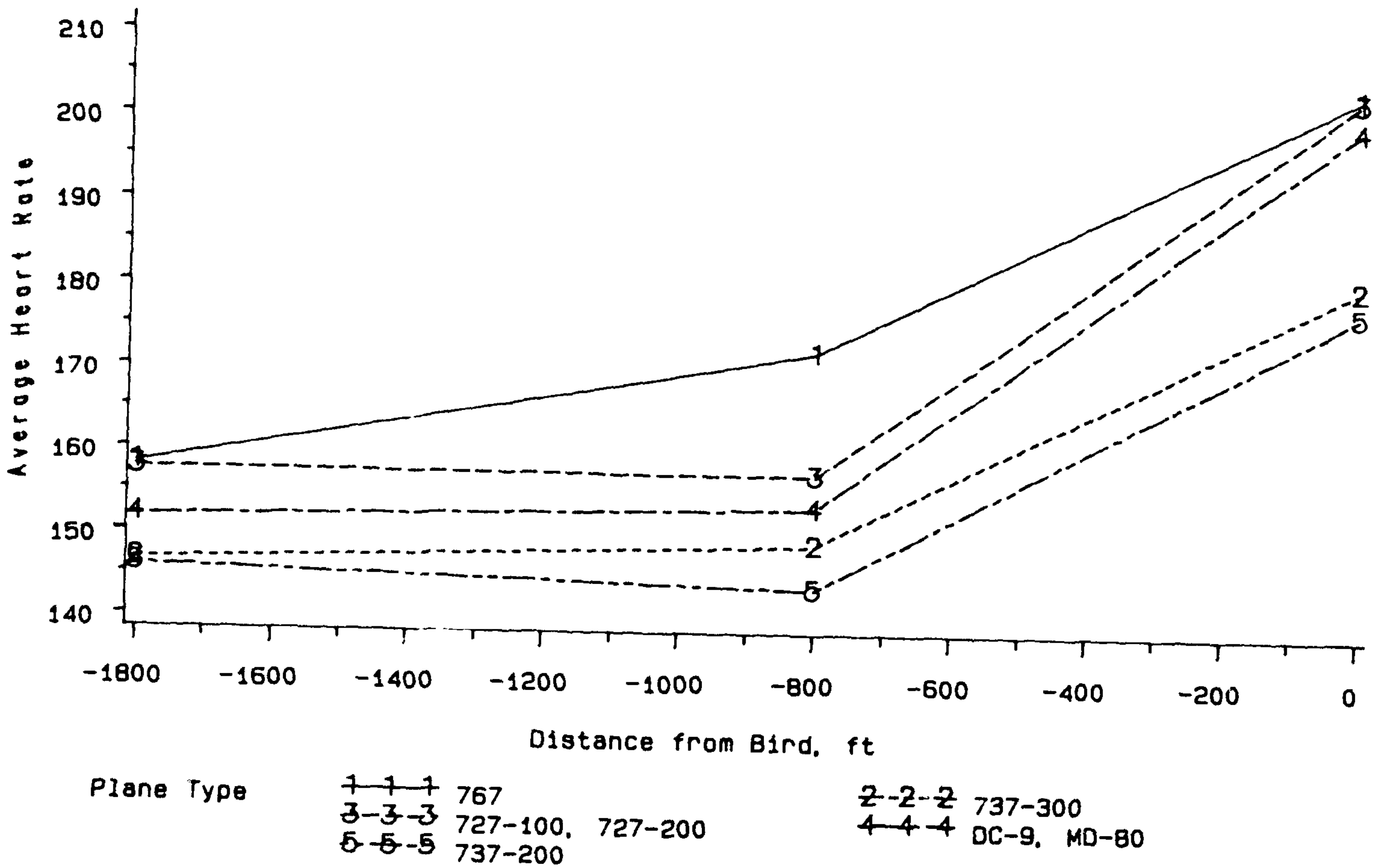


FIGURE 53. AVERAGE HEART RATE VERSUS DISTANCE FROM BIRD (PIGEON)

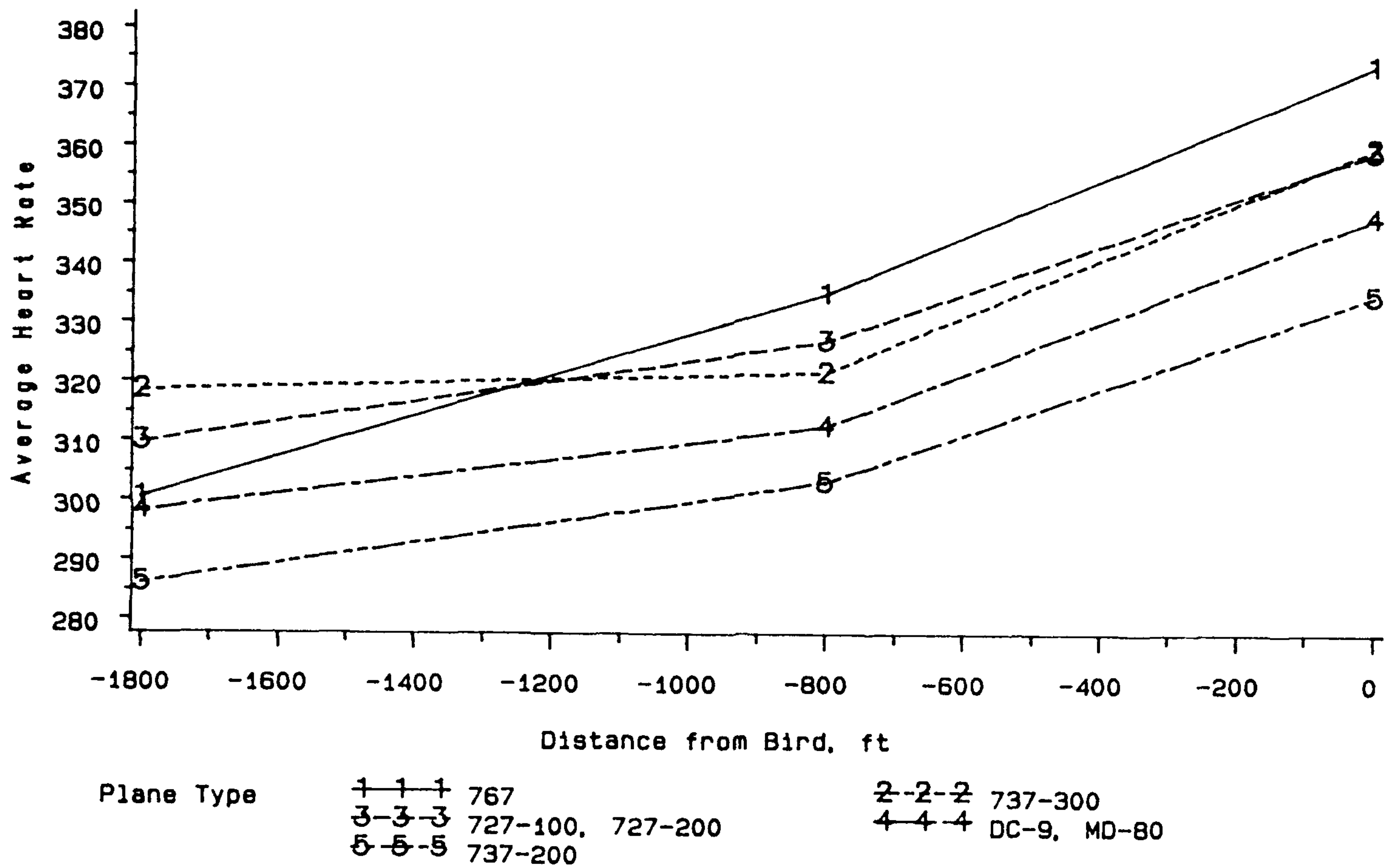


FIGURE 54. AVERAGE HEART RATE VERSUS DISTANCE FROM BIRD (GULL)

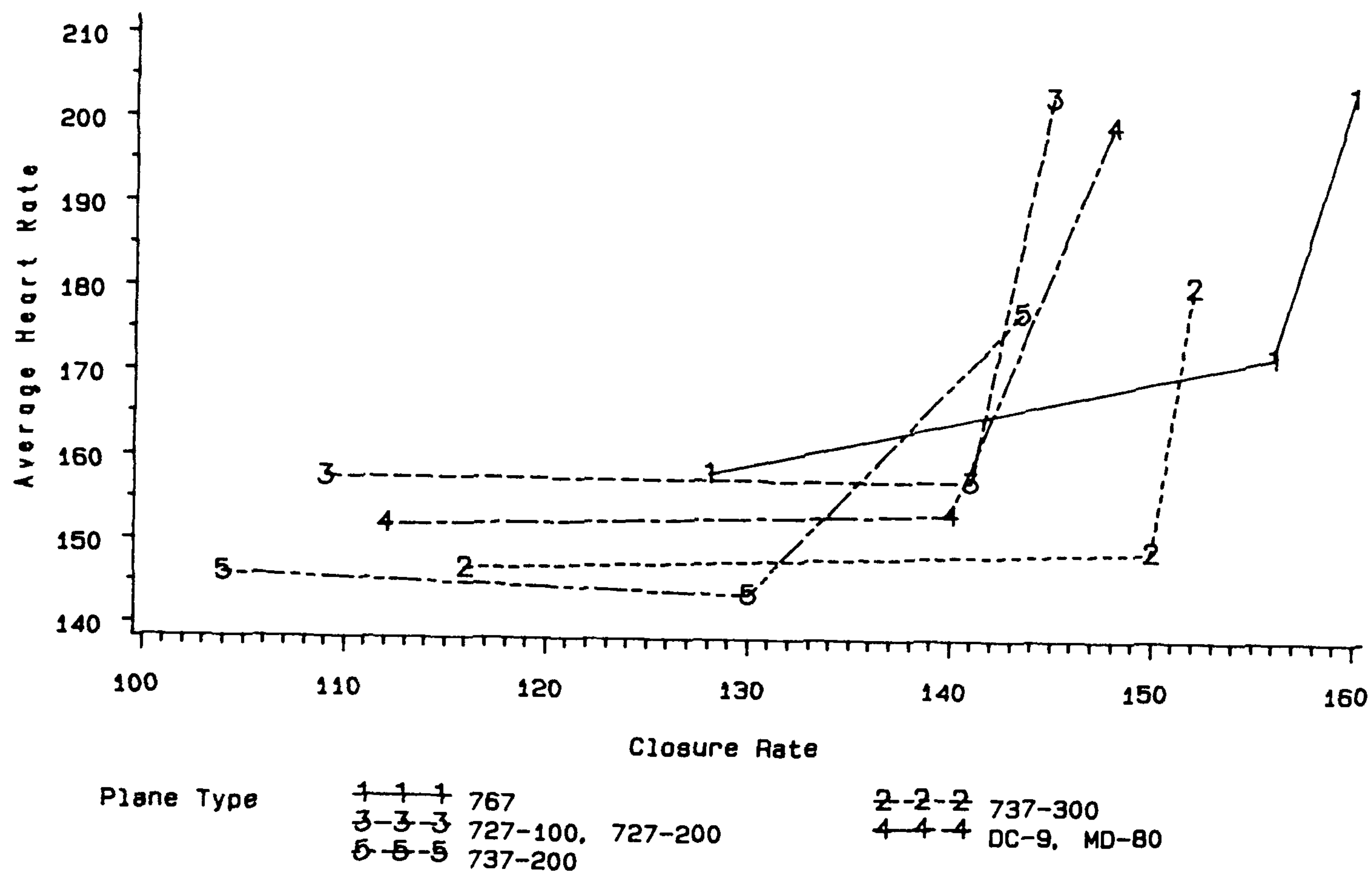


FIGURE 55. AVERAGE HEART RATE VERSUS CLOSURE RATE (AIRCRAFT SPEED MPH) PIGEON

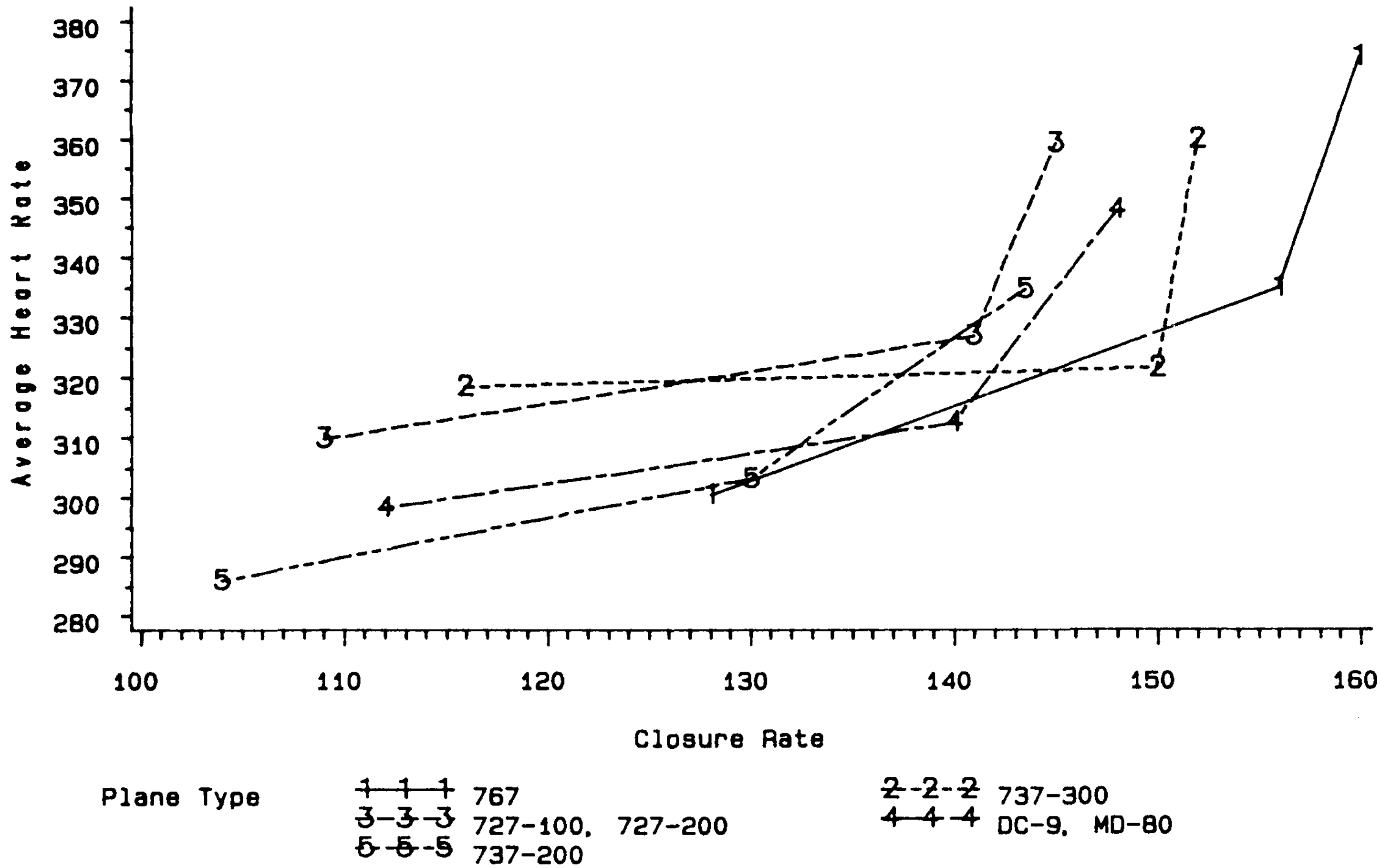


FIGURE 56. AVERAGE HEART RATE VERSUS CLOSURE RATE (AIRCRAFT SPEED MPH) GULL

Leather gloves were required when handling the gulls as the bird's beak and strong pecking bite could break the skin. A styrofoam hood was placed over the gull's eyes during pre-test preparation while installing a harness and ECG transmitter on the bird. The hood was left on the bird during transportation to the airport test site and removed after cages were positioned beside the runway. No special equipment was required while handling the pigeons. Heart rate tracings were recorded on a strip chart recorder prior to each test to check each bird and continuity of equipment.

The normal feed ration was fed after the test when the birds were returned to the holding cage. Appetite and actions of the post-test bird's behavior were monitored to indicate excess stress or health condition.

Guidelines for preparation of the wild bird diets and care were obtained from the San Antonio Zoo and the Committee on Birds at the Institute of Laboratory Animal Resources, National Academy of Sciences (reference 7) and others (references 8,9,10)

CONCLUSIONS.

Aircraft tested included the standard-body 737-200, 737-300, 727-100, 727-200, DC-9, MD-80, and the wide-body 767-100.

Using the maximum heart rate of gulls and pigeons as an indicator of recognition of aircraft, birds respond to wide-body aircraft more than standard-body aircraft while viewing the aircraft during the take-off roll.

Birds exposed to the wide-body aircraft experienced statistically higher maximum heart rates on the average than the standard-body aircraft in every test analysis.

Gulls had a significantly higher average maximum heart rate than pigeons when tested at the aircraft rotation point. Gulls did not indicate by maximum heart rate response as much change as the pigeons during the maximum sound response interval when the data were normalized by control tests.

The maximum sound level (140 dB) of the aircraft did not occur at the test bird location until 3 seconds after the aircraft nose was adjacent to the bird. The feral pigeons were more responsive to the sight-and-sound of the approaching aircraft when compared with sound-only. The gulls response was similar between sight-and-sound and sound-only.

The closure rate of the aircraft from the start of the take-off roll to the test bird location was from 25 to 30 seconds with no apparent recognition of the approaching aircraft, as indicated by increased heart rate response, until the aircraft was within 1000 feet of the bird. With a closure rate of 150 to 200 feet per second during the final 1000 feet, the bird would have 5 seconds to clear the area.

The test birds (gulls and pigeons) recognize the difference between wide-body and standard-body aircraft and indicate, by increased heart rate response, the danger of the approaching aircraft (both wide- and standard-body) during the final rotation phase.

DISCUSSION.

One significant variable not controlled in this study was the location of the test bird in relation to the sight of the aircraft after rotation. The wide-body 767 was always airborne when the test bird location was reached. The 737-300 also was usually airborne but the 727 and DC-9 standard-body aircraft were not always clear of the ground as they passed the birds. The birds appeared to respond much more to the aircraft when the angle changed at rotation.

It is possible the increased response to the wide-body was due to the silhouette shape changes from frontal to wing shape in the bird's viewing angle. All aircraft rotated at a different distance and angle from the bird location and the aircraft passing close to the bird did not have as great an affect on the bird as the larger wide-body aircraft passing over the bird. Additional studies are recommended to verify response of birds to controlled changes of frontal area profile.

The test, as presented, was designed and conducted to be, as close as possible, to a wild population of problem birds located on and around an active airport and exposed to approaching aircraft. For safety purposes, the test birds were contained in small cages. Additional studies are recommended to develop a safe method of testing unrestrained birds. Physiological responses obtained from the caged birds could then be compared with the unrestrained birds. These methods could be used to test various types of early warning devices that could be developed to move birds and mammals away from the dangerous environment of an airport.

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